# WORKSHOP ON
# ENERGY MANAGEMENT IN INDUSTRIAL SECTOR

Sponsored by
**Department of Personnel and Training,**
Government of India

Conducted by
**Tata Energy Research Institute**

At
Vigyan Bhavan, New Delhi
November 24-26, 1986

## Programme

### November 24

| | |
|---|---|
| 0930-1020 | Inaugural Session |
| 0930 | Welcome Address - Dr. R.K. Pachauri, Director, Tata Energy Research Institute |
| 0940 | Inaugural Address - Mr. Lovraj Kumar, Consultant, Advisory Board on Energy |
| 1005 | Remarks on Training Programme - Mr. O.P. Gupta, Director, Department of Personnel and Training |
| 1015 | Vote of Thanks - Mr. V.S. Kothari, Fellow, Tata Energy Research Institute |
| 1020-1045 | Tea/Coffee Break |
| 1045-1100 | Introduction to Programme |
| 1100-1210 | Energy Use Patterns in the Industrial Sector and Policy Implications<br>Dr. R.K. Pachauri |
| 1210-1320 | Energy Conservation Concepts<br>Mr. V.S. Kothari |
| 1320-1410 | Lunch Break |
| 1410-1520 | Plant-Level Energy Management<br>Mr. S. Padmanabhan |
| 1520-1540 | Tea/Coffee Break |
| 1540-1700 | Group Discussion - Energy Management in Industry : Personal Experiences |
| 1830-2000 | Reception by Director, Tata Energy Research Institut<br>at 7, Jor Bagh, New Delhi |

**November 25**

| | |
|---|---|
| 0930-1040 | Energy Conservation in Petroleum Refining Industry : Opportunities and Achievements<br>Mr. M.K. Joshi and Mr. V. Baskaran |
| 1040-1100 | Tea/Coffee Break |
| 1100-1210 | Energy Conservation in Paper Industry<br>Mr. H.H. Jethanandani |
| 1210-1320 | Energy Conservation in Steel Industry<br>Dr. S.M. Aeron |
| 1320-1410 | Lunch Break |
| 1410-1520 | Case Studies in Energy Conservation<br>Mr. Sudhir Mohan |
| 1520-1540 | Tea/Coffee Break |
| 1540-1700 | Group Discussion - Technical, Economic and Policy Issues and Barriers to Energy Conservation in Industry |

**November 26**

| | |
|---|---|
| 0930-1040 | Industrial Cogeneration<br>Mr. V.S. Kothari |
| 1040-1100 | Tea/Coffee Break |
| 1100-1210 | Industrial Sector Energy Use Models<br>Ms. L. Srivastava |
| 1210-1320 | Policy Measures for Energy Conservation<br>Mrs. S. Chandra |
| 1320-1410 | Lunch Break |
| 1410-1530 | Panel Discussion - Formulation and Implementation of Policies to Accelerate Energy Conservation in Industry<br>Panelists : Mrs. S. Chandra<br>Mr. M.K. Sridhar<br>Mr. P. Sengupta<br>Mr. J. Ramesh |
| 1530-1540 | Tea/Coffee Break |
| 1540-1630 | Feedback and Programme Evaluation |

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# ENERGY USE PATTERNS IN THE INDUSTRIAL SECTOR AND POLICY IMPLICATIONS

by

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Director,

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7, Jor Bagh, New Delhi 110 003.

## BACKGROUND

Since the first oil price shock in 1973-74 and the second one subsequently in 1979-80, a world-wide effort has been launched to develop more efficient methods for energy use and conversion processes. Several outstanding examples can be quoted of achievements in improving energy efficiency in several countries of the world, but most of these examples remain confined to the developed countries. In the case of the EEC countries for instance during the period between 1973-1983 economic growth has taken place to the extent of 23% with an actual decline of energy consumption of 6%. In the case of Japan, achievements have been of an even higher order, with growth rates averaging close to 5% since the first oil price shock, and this has been accompanied by an actual decline in energy consumption. In the developing world in general and India in particular, however, while the potential for improved management of energy and attainment of higher energy efficiency remains very high it remains virtually untapped. Given the growth in capital intensity of the energy supply industry, it is imperative that a serious effort be launched nationwide for conservation of energy and attainment of higher efficiency in energy use. The prime candidate for efforts in this direction is the industrial sector of the country,since the immediate potential for savings in energy use with so called "housekeeping" measures is of the order of 15%. Further savings are possible with moderate levels of investment, but the rate of return from these investments is attractively high.

## INTERNATIONAL COMPARISONS

In order to assess the overall nature of India's pattern of energy consumption we present in Table 1, shares of oil in total commercial energy demand for 1973-1983 for selected Asian countries. Given India's endowment of coal resources, the share of oil appears somewhat high, and in particular the decline in this share between 1973-1983 is not appreciable. Table 2 shows energy and oil per capita for the same group of countries, and here it would be seen that India has increased its energy consumption per capita somewhat faster than oil consumption per capita. Accordingly, the slow increase in oil consumption does show the effects of conservation and the results of a policy of reducing dependence on oil in the Indian economy. Further, Table 3 shows energy and oil demand as a ratio of GDP.

As against the above aggregate figures, Table 4 shows energy and oil intensity in the industrial sector. These figures stand out in contrast with aggregate figures for per capita consumption and for the economy as a whole. The Indian industrial sector is only second to China in energy intensity, and what is more serious, shows an increase which averages 3.7% during the period 1978-83, a period when conservation efforts should have been bearing fruit, particularly in response to the second oil price shock. Undoubtedly, India's indus-

### Table 1 Shares of Oil in Total Commercial Energy Demand (percent)

| | *1978* | *1988* |
|---|---|---|
| Bangladesh | 52* | 40 |
| China | 19 | 19 |
| India | 33 | 30 |
| Indonesia | 87 | 76 |
| Korea | 64 | 59 |
| Malaysia | 94 | 89 |
| Pakistan | 47 | 35 |
| Philippines | 96 | 82 |
| Taiwan | 69 | 59 |
| Thailand | 91 | 78 |

* 1977

### Table 2 Energy and Oil Demand per Capita (TOE per 1000 persons)

| | ENERGY | | | OIL | | |
|---|---|---|---|---|---|---|
| | *1978* | *1988* | *AAGR* | *1978* | *1988* | *AAGR* |
| Bangladesh | - | 39 | - | - | 15 | - |
| China | 304 | 446 | 3.8% | 57 | 83 | 3.8% |
| India | 130 | 180 | 3.3% | 43 | 54 | 2.3% |
| Indonesia | 86 | 184 | 7.6% | 75 | 139 | 6.2% |
| Korea | 644 | 1185 | 6.1% | 413 | 699 | 5.3% |
| Malaysia | 439 | 741 | 5.2% | 412 | 661 | 4.7% |
| Pakistan | 90 | 179 | 6.9% | 42 | 63 | 3.9% |
| Philippines | 272 | 261 | -0.4% | 260 | 213 | -2.0% |
| Taiwan | 910 | 1625 | 5.8% | 627 | 966 | 4.3% |
| Thailand | 216 | 289 | 2.9% | 197 | 226 | 1.4% |
| Average | 231 | 338 | 3.8% | 73 | 104 | 3.5% |

### Table 3 Energy and Oil Demand and GDP (TOE per 1980 US $)

| | ENERGY | | | OIL | | |
|---|---|---|---|---|---|---|
| | *1978* | *1988* | *AAGR* | *1978* | *1988* | *AAGR* |
| Bangladesh | - | 258 | - | - | 102 | - |
| China | 1607 | 1480 | -0.8% | 302 | 276 | -0.9% |
| India | 677 | 778 | 1.4% | 222 | 232 | 0.4% |
| Indonesia | 246 | 349 | 3.5% | 215 | 264 | 2.0% |
| Korea | 608 | 629 | 0.3% | 390 | 371 | -0.5% |
| Malaysia | 344 | 387 | 1.2% | 323 | 345 | 0.7% |
| Pakistan | 404 | 634 | 4.5% | 191 | 222 | 1.5% |
| Philippines | 467 | 354 | -2.8% | 416 | 290 | -4.3% |
| Taiwan | 605 | 649 | 0.7% | 417 | 386 | -0.8% |
| Thailand | 415 | 367 | -1.2% | 379 | 288 | -2.0% |
| **Average** | 911 | 910 | - | 289 | 280 | -0.3% |

trial base is very different from several countries of the region excluding China, and therefore a direct comparison with say Indonesia or the Philippines would not be valid. But on the other hand a highly industrialised nation like the Republic of Korea, or for that matter Taiwan, shows much lower energy intensities despite the heavy industrial base in these two states. Even more notable is the reduction in energy intensity that took place between 1978-1983 in the case of the Philippines, Republic of Korea and Thailand. The major issues concerning energy use in the industrial sector that emerge from these figures and a deeper study of the reasons for existing disparities brought out in Table 5 can be listed as follows :

1) The entire structure of production in the country needs to be evaluated in terms of intensity of energy use and implied effects on demand for energy.

2) The choice of technologies to be adopted both in those industries which have a high intensity of energy use per unit of production and those industries which have a high volume of energy use on account of large scale output, needs to be driven by a concern for energy efficiency.

3) A programme for immediate implementation of housekeeping measures to improve energy efficiency and large scale retrofits, at least where capital expenditures are low, has to be taken in hand seriously.

## PATTERNS OF ENERGY USE IN INDIA'S INDUSTRIAL SECTOR

The problem of energy efficiency improvements is of course endemic throughout the developing world and several actions and measures can be identified to bring about a substantial improvement in the existing situation. The potential of some of these measures was studied by the World Bank and identified as shown in Table 6. It would be seen that retrofitting and technical improvements are expected to yield the largest savings in energy use.

To see the potential for some of these savings as applicable to India, we would now look at patterns of energy consumption and overall characteristics of energy use in India's industrial sector. These can be seen in terms of specific forms of energy consumed. Firstly, in the case of electricity, of which almost 60% is consumed by the industrial sector, the elasticity of electricity consumption has remained much higher than in several developed as well as developing countries. The figures for this variable computed as changes in consumption with respect to changes in value added in the industrial sector (including mining and manufacturing) at constant 1970-71 prices shows the following values :

Table 4 Industrial Energy and Oil Intensity
(TOE per 1980 US $ of Value Added)

| | ENERGY | | | OIL | | |
|---|---|---|---|---|---|---|
| | *1978* | *1988* | *AAGR* | *1978* | *1988* | *AAGR* |
| Bangladesh | 402 | 326 | -4.2% | 161 | 91 | -12% |
| China | 2435* | 2335 | -1.4% | - | - | - |
| India | 733 | 881 | 3.7% | 120 | 124 | 0.7% |
| Indonesia | 247 | 369 | 8.1% | 192 | 237 | 4.2% |
| Korea | 453 | 448 | -0.2% | 307 | 177 | -11.1% |
| Malaysia | 333 | 331 | -0.1% | 259 | 243 | -1.3% |
| Pakistan | 623 | 558 | -2.2% | 51 | 58 | 2.5% |
| Philippines | 394 | 297 | -5.7% | 337 | 218 | -8.7% |
| Taiwan | 517 | 459 | -2.4% | 263 | 200 | -5.5% |
| Thailand | 282 | 228 | -4.2% | 216 | 138 | -8.9% |
| Average | 488 | 506 | 0.7 | 218 | 175 | -4.3% |

* 1980

Table 5

| Period | Elasticity Coefficient for Electricity Consumption |
|---|---|
| 1959/60 - 1964/65 | 1.6825 |
| 1964/65 - 1969/70 | 2.8102 |
| 1969/70 - 1975/75 | 1.1659 |
| 1974/75 - 1979/80 | 1.3244 |
| 1979/80 - 1984/85 | 1.3959 |
| 1959/60 - 1984/85 | 1.6405 |

## TABLE - 6

### Potential savings in commercial energy consumption in developing countries, 1980

(million of barrels per day of oil equivalents)

| | | Savings from: | | | | |
|---|---|---|---|---|---|---|
| | Projected consumption | Pricing policies | Taxes and regulations | Retrofitting and technical improvemeans | Interfuel substitution | Total |
| Electric power* | 7.3 | 0.1 | -§ | 0.6 | 0.1 | 0.8 |
| Agriculture | 1.7 | -§ | -§ | 0.1 | -§ | 0.1 |
| Households | 6.6 | 0.3 | 0.1 | 0.1 | 0.5 | 1.0 |
| Transport | 8.4 | 0.1 | 0.1 | 0.7 | 0.2 | 1.1 |
| Industry | 9.7 | 0.2 | 0.2 | 1.2 | 0.3 | 1.9 |
| Other | 0.6 | 0.1 | -§ | -§ | -§ | 0.1 |
| Total | 34.3 | (0.8) | (0.4) | (2.7) | (1.1) | 5.0 |

* Includes energy consumed in generation, station use, losses in transmission, and distribution.

§ Less than 0.05

Source : World Bank estimates.

It would be observed that the largest increase in electricity intensity took place during the period 1964-65 to 1969-70. This was the period when a major shift took place in the heavy industries base of the industrial sector. If we were to project past levels of elasticity of electricity consumption with respect to industrial output, then with a 6.8% compound annual rate of growth in industrial output during the 7th Five Year Plan, we would arrive at demand for electricity of 124 billion Kwh. A simplisitic assumption about constant electricity elasticity, however, would not be valid in making future predictions. For instance, if we were to consider the perspective plan brought out by the Planning Commission with the 7th Five Year Plan, the structure of the industrial sector in the year 1999-2000 is expected to be very different from the present. The manufacturing sector itself is likely to increase gross value added from 15% of total output in 1984-85 to 20% in 1999-2000. This increase will be attained largely by a rapid increase in the output of petrochemicals and plastics, fertiliser, aluminium, electronics, telecommunication equipment and components. In the case of the electronics industry alone, it is expected that output would increase 25 times by the year 2000 over the level attained in 1984-85. The demand for energy, therefore, would be highly sensitive to the kind of industrialisation strategies that the country adopts and pursues. If a high value added manufacturing strategy based on low energy consumption industries is pursued then a consequent decline in the electricity elasticity would be possible.

In the recent document indicating the perspective for 2004-2005 the Advisory Board on Energy has estimated electricity demand for the industrial sector at 280 billion Kwh and 367 billion Kwh for 1999-2000 and 2004-2005 respectively. If these estimates are to hold, then the demand for electricity in 1994-95 can be interpolated at around 185 billion Kwh, showing an increase of almost 50% during the 8th Five Year Plan period. Translated into additional generating capacity, this would amount to approximately 16,000 MW. If current estimates of cost per unit capacity are to be assumed, this growth of the industrial sector would imply a capital requirement of approximately Rs.20,000 crores by way of capacity additions in the power sector. It needs to be assessed whether efforts in conservation would result in a lower per unit cost for reductions in capacity required keeping output constant.

Coal use in the industrial sector is mainly in the form of coking coal for the steel industry and non-coking coal for the cement, paper and paper board, newsprint, vanaspati and brick industries. A large cluster of small industries generally accounts for around 20% of total coal consumption, but unfortunately disaggregated data on these is not available. Estimates for production in the iron and steel industry are set at approximately 28 million tonnes of hot metal in the year 2004-05. If there was to be no improvement in the efficiency of coking coal use in the industry, then the demand in the years 1989-90, 1994-95, 1999-2000 and 2004-2005 would be 41.1 million tonnes, 60 million tonnes, 75 million tonnes and 88 million tonnes respectively.

A minimum reduction of about 10% is possible in the consumption of these quantities even with existing technologies and much larger reductions are possible with improved processes in the future.

As regards consumption of non-coking coal, the biggest users are the cement, fertilisers, papers and paper board and brick industries. Almost all the capacity to be added in future in the cement industry would rely on the dry process. But energy savings would be possible if Pozzolana cement is to be produced instead of ordinary Portland cement. Also, by using substitutes like lime, lime-pozzolana or fly ash mixtures, energy requirements can be reduced even further. In the case of nitrogenous fertilisers, future plants are not likely to be coal based, and as such the share of coal use by the fertiliser industry is expected to go down. In the case of the paper industry efficient heat recovery and cogeneration systems can normally reduce total coal requirement by 25-35% per tonne of paper produced.

As far as petroleum products are concerned, the industrial sector uses oil products generally at a rate of 0.004 Kg per rupee of value added. If this norm was to continue unchanged then the demand in the year 2004-2005 would be 16.62 tonnes of petroleum products. Unfortunately data on use of petroleum products in the industrial sector (and most other sectors) is hardly adequate to make possible any analysis of consumption patterns and changes therein. A major effort in carrying out periodic surveys of consumption of oil products needs to be taken in hand on a regular basis.

On the basis of the above projections, we can predict the demand for coal and petroleum products as shown below in Table 7.

Table 7

| Year | Requirement of Coal in the Industries Sector (Million Tonnes) |
|---|---|
| 1989-90 | 89.2 |
| 1994-95 | 120.0 |
| 1999-00 | 150.0 |
| 2004-05 | 188.0 |
| Year | Requirement of petroleum products in Industries as Fuel (in Million Tonnes) |
| 1989/90 | 6.11 |
| 1994/95 | 8.53 |
| 1999/00 | 11.81 |
| 2004/05 | 16.62 |

It is evident from the rapid rate of growth shown in these figures that demand for energy in the industrial sector may not be met, given the constraints not only in the coal and petroleum supply industry but also other attendant infrastructure such as transportation. Consequently energy conservation assumes an importance overriding other elements of a long term energy policy.

# ENERGY CONSERVATION CONCEPTS

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NEW DELHI

WORKSHOP ON ENERGY MANAGEMENT IN INDUSTRIAL SECTOR

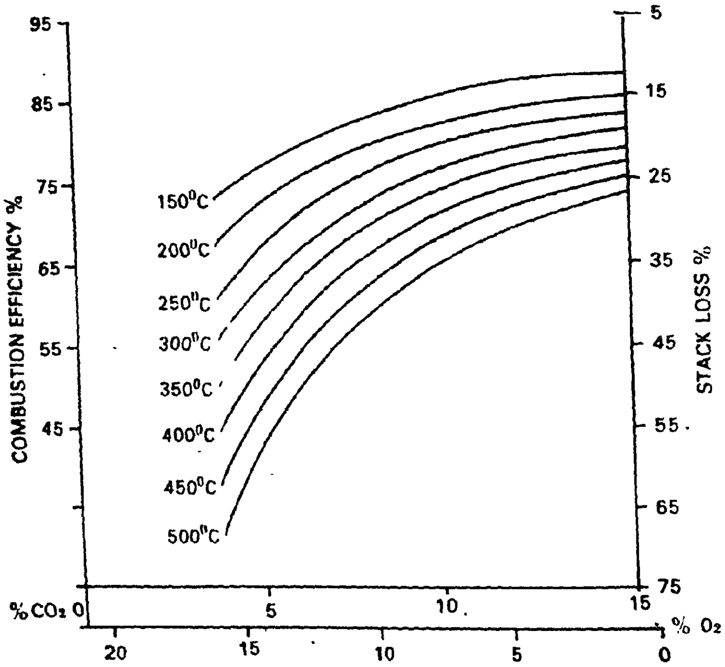
NOVEMBER 24-26, 1986

## AREAS FOR ENERGY CONSERVATION

- Combustion Equipment
- Steam System
- Electrical System
- Process Equipment
- Process Modifications
- Utilities and Off-Site Facilities
  - Compressed Air
  - Refrigeration
  - Cooling Water
  - Fuel Handling
- Services
  - Air Conditioning
  - Lighting

# HEAT LOSSES IN COMBUSTION

- Hydrogen in Fuel
- Moisture in Fuel and Air
- Dry Products of Combustion
    - Excess Air
    - Flue Gas Temperature



- Unburnt Combustibles

# HEAT LOSSES IN COMBUSTION EQUIPMENT

- Generic Losses
  - Losses in Combustion
  - Radiation
  - Openings
  - Air Infiltration

- Equipment or Equipment Design Specific Losses
  - Product Support/Conveyor Losses
  - Materials/By-Products e.g. blowdown (boiler), slag (blast furnace)
  - Cycling Losses in Batch Operation

# IMPROVING EFFICIENCY OF COMBUSTION EQUIPMENT

- Operating Practices, e.g.
  - Burner condition and performance
  - Excess air
  - Flame shape and heat distribution pattern
  - Heat transfer surfaces
  - Furnace temperature
  - Furnace draft
  - Loading

- Excess Air Control and Reduction

- Waste Heat Recovery

- Insulation Enhancement/Replacement

- Combustion System
  - Low excess air burners
  - High velocity burners
  - Self-recuperative burners

# WASTE HEAT RECOVERY

- Equipment modifications/additions are required

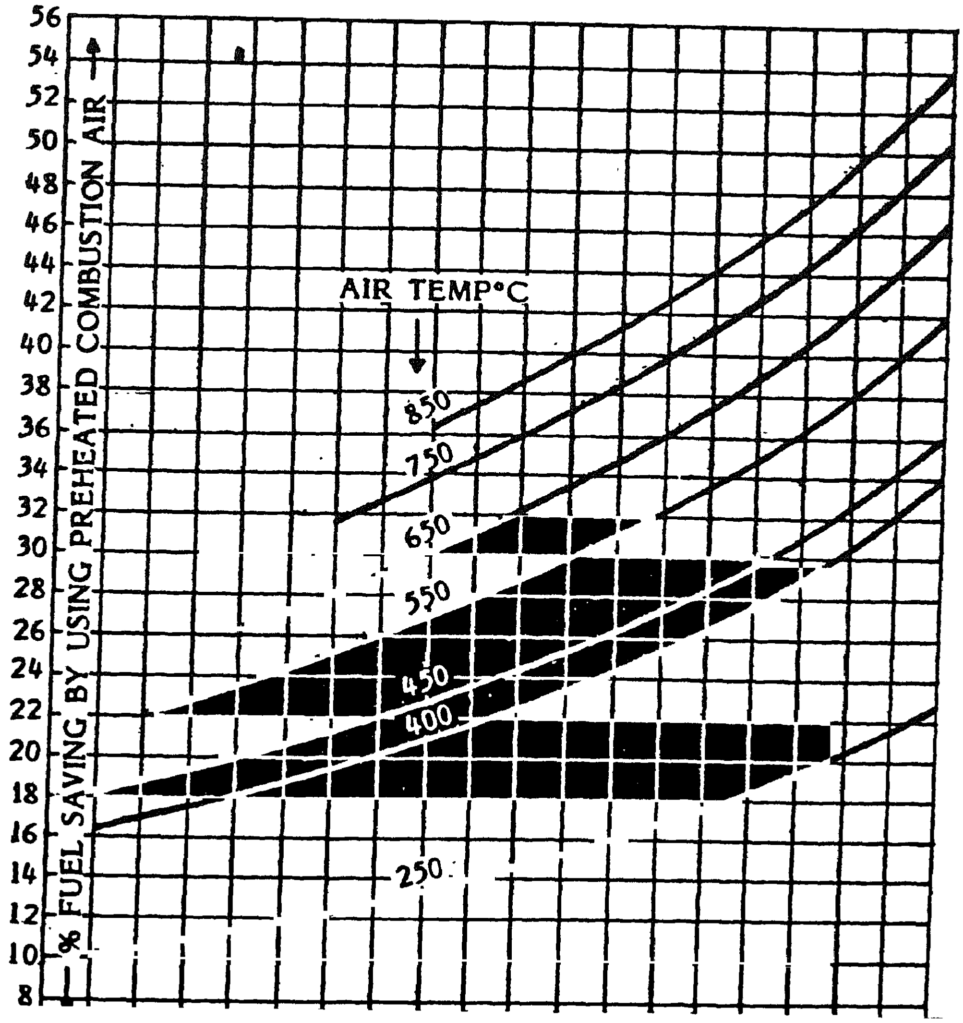
- Three general methods

  - Preheat product, i.e. increase heat transfer to product within equipment, e.g. economiser on boiler, convection section on refinery heater, preheat zone on steel reheat furnace

  - Preheat combustion air

  - Heat another fluid or product stream, e.g. water, process liquids (steam can be raised by heating water in waste heat boiler)

**APPROXIMATE FUEL SAVINGS AS FUNCTION
OF FURNACE EXIT TEMPERATURE
AND AIR PREHEAT TEMPERATURE**

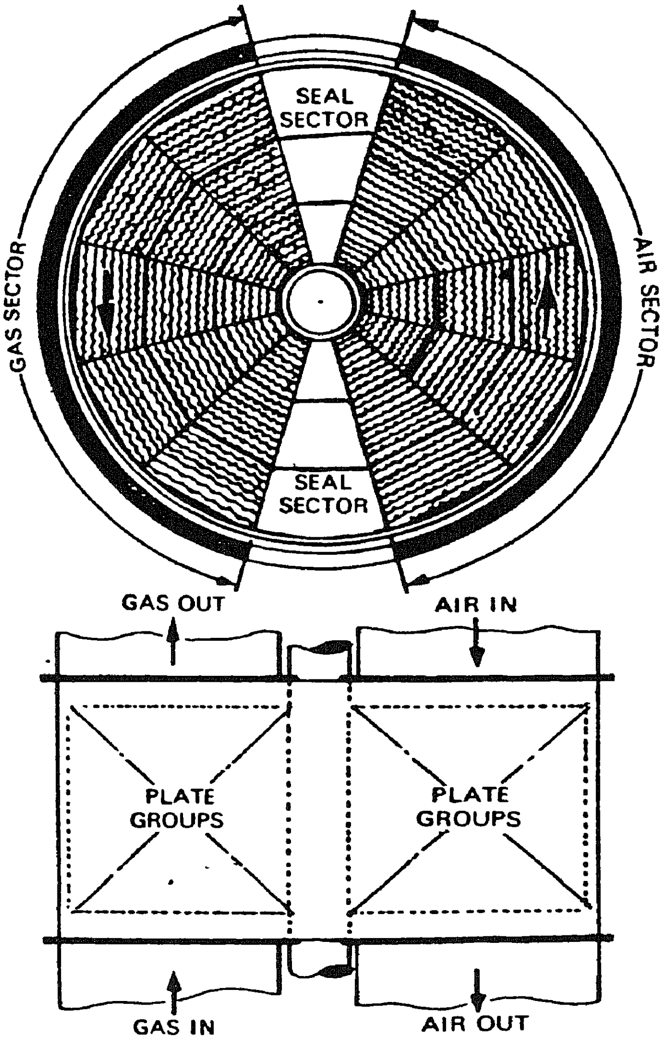


# WASTE HEAT RECOVERY EQUIPMENT

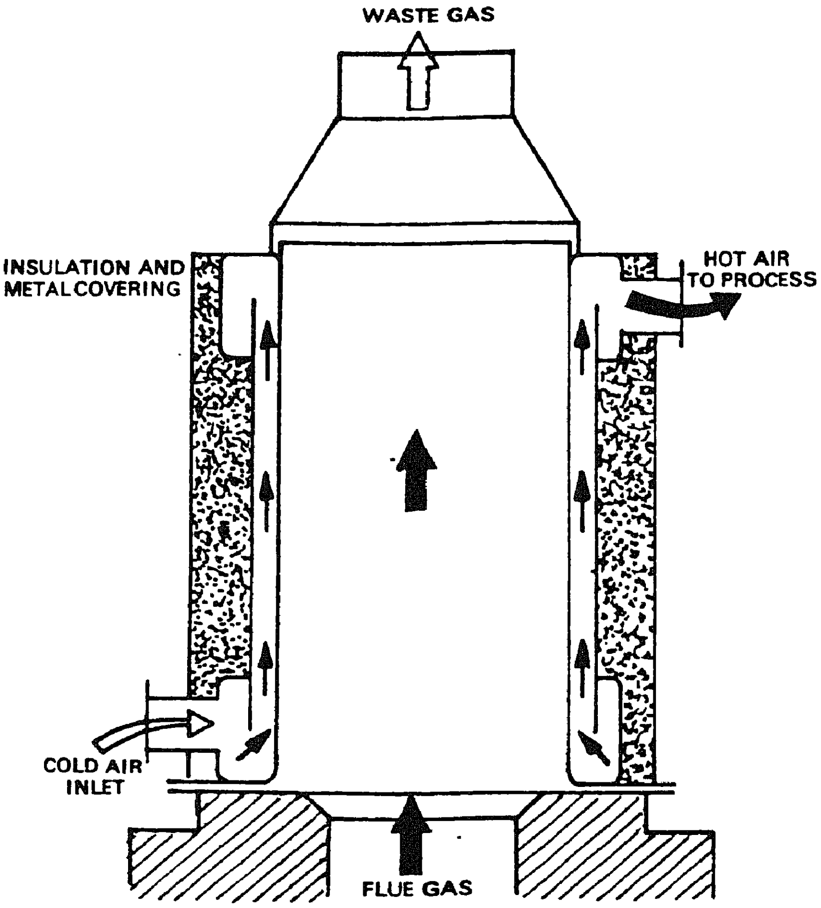
- Classifications can be based on
    - Equipment type, e.g. recuperator, economiser
    - Mode of heat transfer, e.g. radiation, convection
    - Flow configuration, e.g. parallel flow, counter flow, cross flow
    - Material, e.g. metallic, ceramic

- Equipment Types
    - Regenerator
    - Recuperator
    - Heat Pipe
    - Waste Heat Boiler
    - Economiser
    - Spray Recuperator

# WASTE HEAT RECOVERY EQUIPMENT

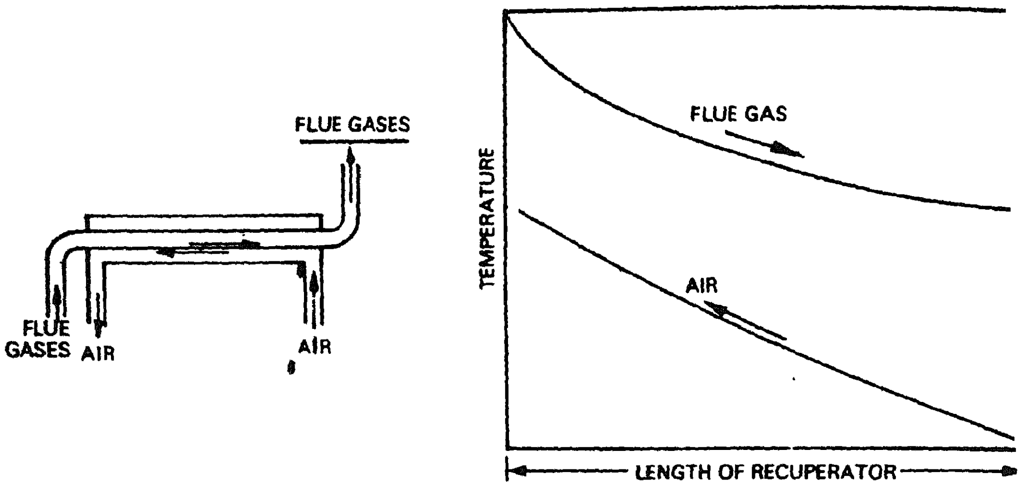


REGENERATOR

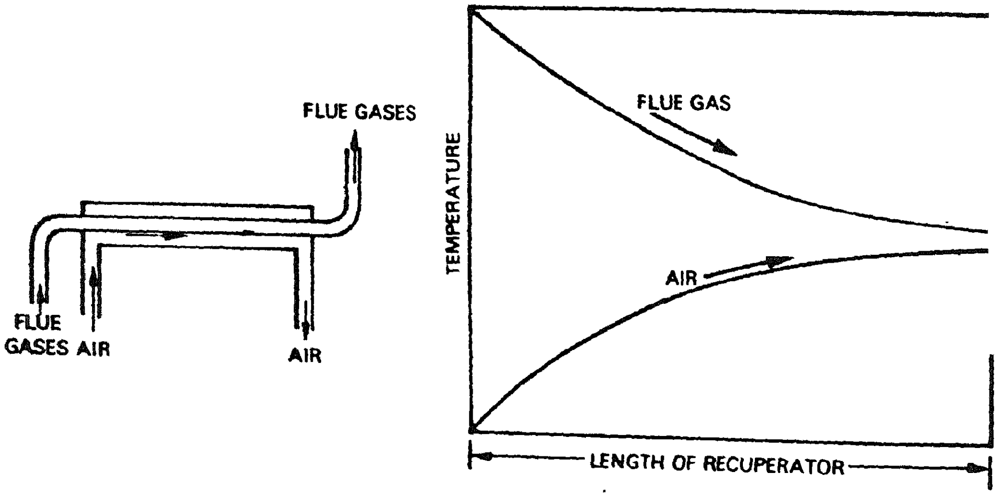


METALLIC RADIATION RECUPERATOR

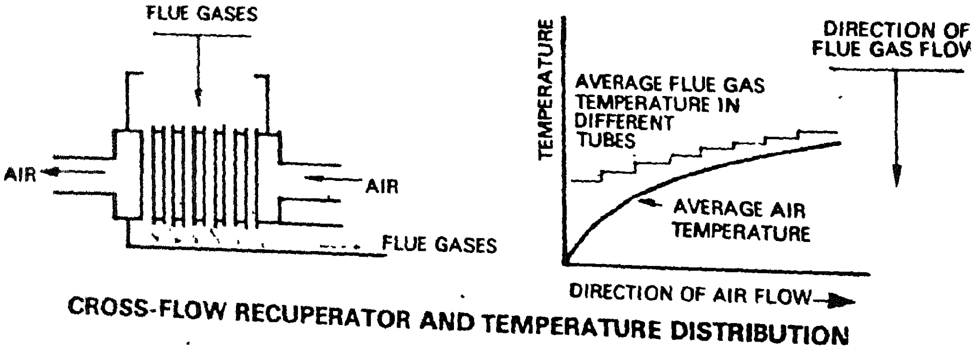
# WASTE HEAT RECOVERY EQUIPMENT



COUNTER-FLOW RECUPERATOR AND TEMPERATURE DISTRIBUTION.



PARALLEL-FLOW RECUPERATOR AND TEMPERATURE DISTRIBUTION.



CROSS-FLOW RECUPERATOR AND TEMPERATURE DISTRIBUTION

TYPES OF FLOWS AND TEMPERATURE DISTRIBUTION

# STEAM SYSTEM

- Steam Leaks and Vents

- Steam Traps

- Insulation

- Condensate Recovery

- Flash Steam Recovery

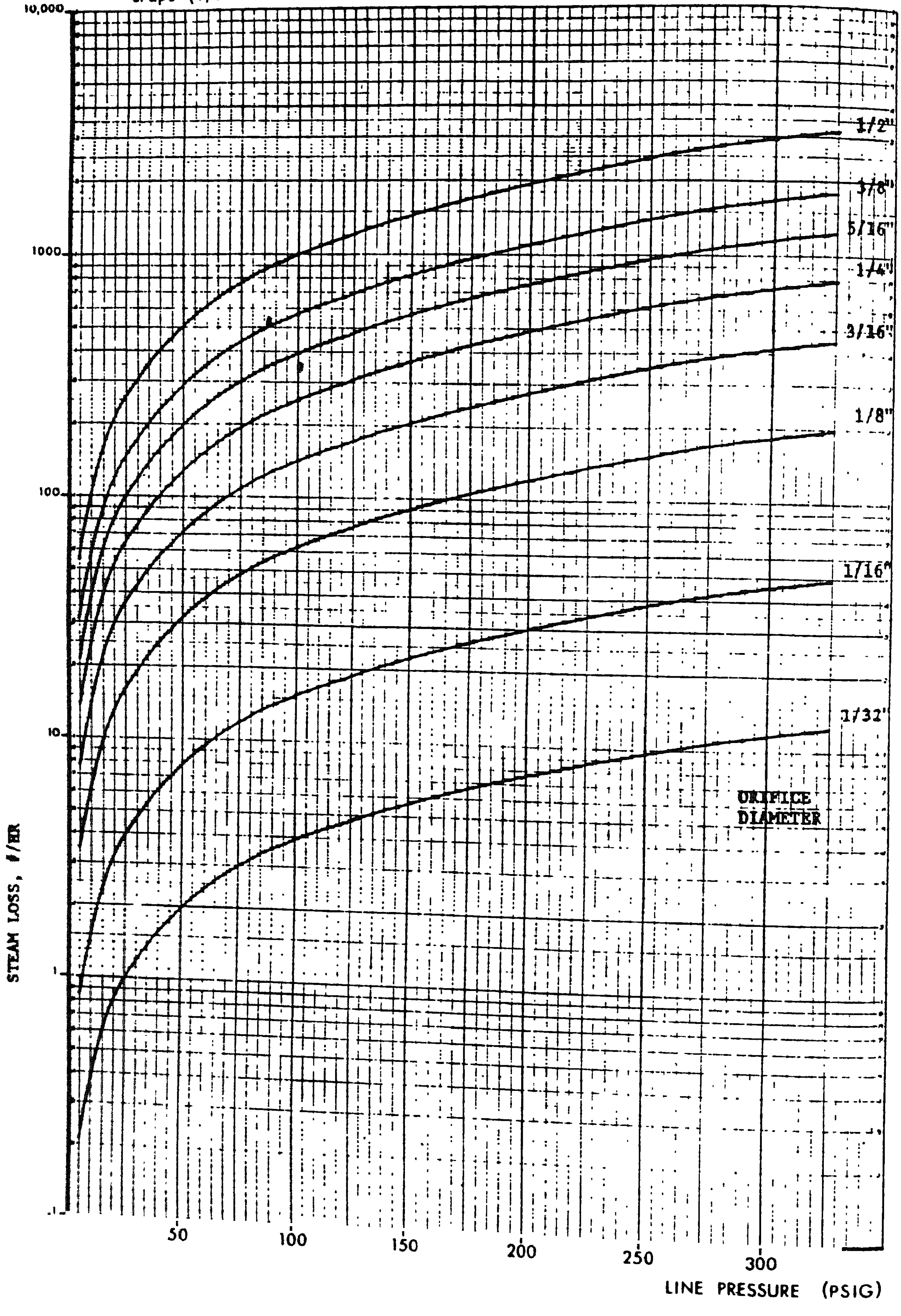
- Boiler Blowdown

- Pressure Reducing Valves

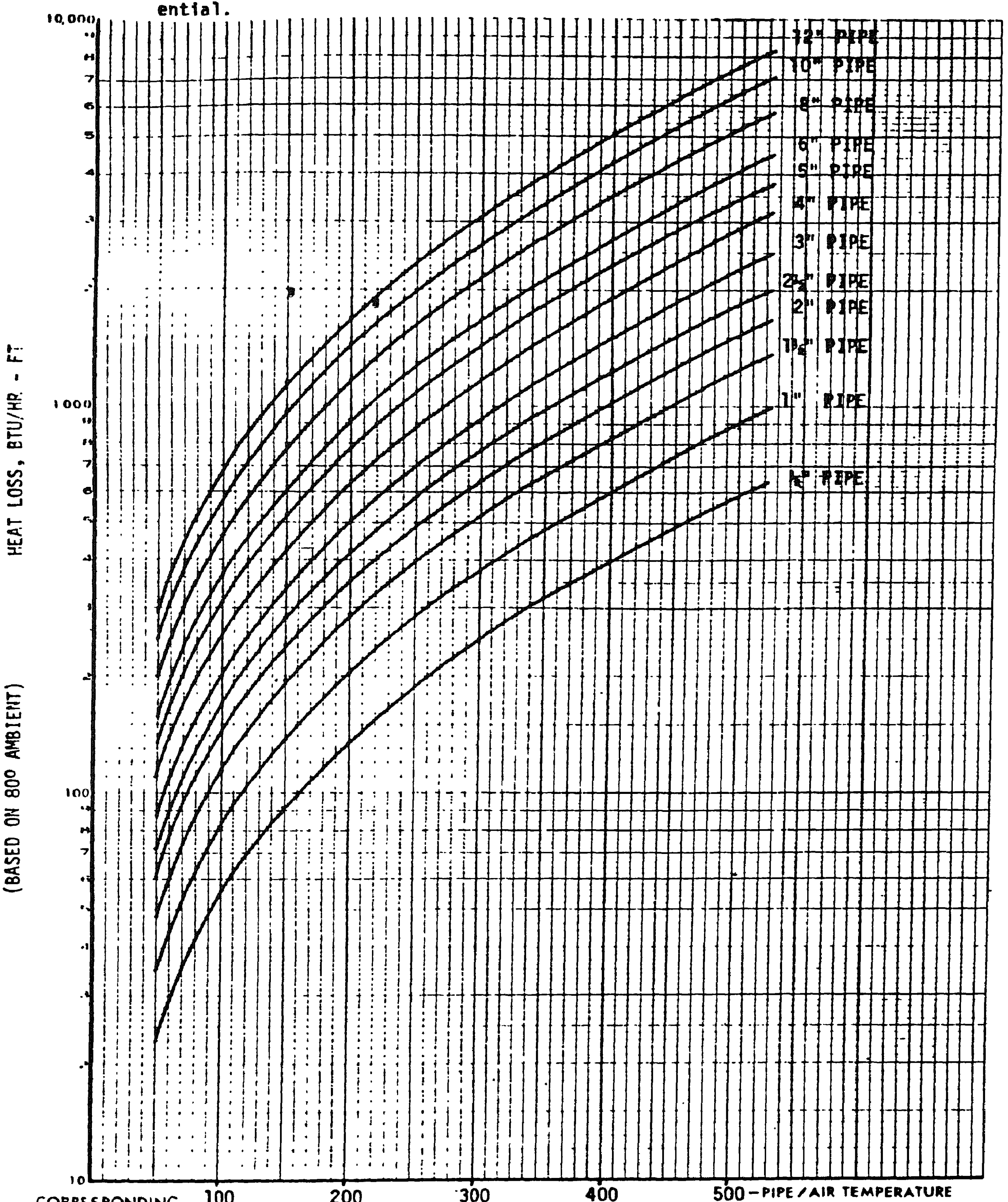
- Proper Steam Utilisation

  - Maintaining steam quality (dryness)
  - Proper utilisation of directly injected steam
  - Proper air venting
  - Steam utilisation in process at lowest practical pressure

STEAM LEAK LOSSES-calculated heat losses through steam leaks or failed traps (1/32" dia. - ½" dia.) as a function of steam line pressure.



UNINSULATED PIPE HEAT LOSS-calculated heat losses per lineal foot from ½" through 12" pipe for a 100°F. - 500°F. pipe-room air temperature differential.



# ELECTRICAL SYSTEM

- Greatest savings through proper management of electrical loads

- Electrical distribution system - savings realisable through elements of proper system design, e.g.
  - Selection of voltage levels
  - Conductor sizing
  - Load centre transformers

- Electric Motors
  - Largest users of electricity in industr
  - Performance/Efficiency depends on
    - Motor characteristics, e.g. size, type, speed etc.
    - Application, e.g. actual operating load, duty cycle etc.
    - Service conditions, e.g. voltage variation, voltage unbalance
  - Efficiency improvement measures
    - Proper load and application matching
    - Variable speed drives
    - Power factor correction
    - Replacement by more efficient motors (energy efficient motors)

- Lighting
  - Reduction in illumination levels wherever possible
  - Turning off lights when not needed
  - Using efficient light sources, e.g. fluorescent lights, sodium vapour lamps

- Power Factor
  - Poor power factor results in greater kilovolt-ampere (kV) load which limits permissible kilowatt (kW) load on utility distribution system
  - Low lagging power factors improved by applying capacitances

- Electrical Load Management
  - Knowledge of utility rate schedule
  - Development of plant electric demand correlated with plant operation
  - Identification of peaks and causes
  - Peak demand reduction measures
    - Rescheduling operations to lower demand periods
    - Sequencing to spread effect over longer time, e.g. startups of equipment
    - Temporary curtailment of loads associated with 'reservoirs', e.g. air compressors, induction furnaces, air conditioning equipment etc.

  - Overall load reduction
    - Replacement of oversized motors
    - Replacement of existing motors by energy efficient motors
    - Lighting efficiency and load

# PROCESS EQUIPMENT

- Proper selection, operation and maintenance affect efficiency of equipment such as heat exchangers, pumps, compressors, turbines, distillation columns, evaporators etc.

- Some examples
  - Monitoring heat exchanger surface fouling
  - Maintaining lowest possible condenser pressure to improve condensing turbine heat rate
  - Substituting multiple effect evaporator for single effect
  - Matching capacity and head characteristics of pump or compressor to requirement by reducing impeller diameter, driver speed or driver rating

# PROCESS MODIFICATIONS FOR ENERGY CONSERVATION

- Most of the energy consumed in a plant is transferred to meet a process requirement for work and/or heat

- Approach to Process Analysis
  - How is energy utilised or generated within the process ?
  - Are reductions in levels of energy use possible ?
  - Can an alternative process or processing scheme be used ?
  - What are the interactions of energy, environment, and economics associated with potential changes ?
  - What effects would potential changes have on product quality and quantity ?

- Second Law Analysis
  - Second Law of Thermodynamics - Conversion of energy from one form to another always results in a net loss of quality
  - Actual conversion from heat into work is always less than the available work
  - High temperature heat should not be degraded into low temperature heat without first extracting work

- Examples
  - Heat integration of available energy sources and sinks
  - Power recovery from pressurised streams

# UTILITIES AND OFF-SITE FACILITIES

- Compressed Air System
  - Operating pressure(s)
  - Types and sizes of compressors
  - Capacity and load matching
  - Leaks and vents
  - Compressed air users/requirements

- Refrigeration Equipment
  - Types of compressors and controls
  - Operating temperature
  - Chiller/Condenser performance
    - Operate at highest chiller pressure/temperature and lowest condenser pressure/temperature
  - Condenser control

- Cooling Towers
  - Operating conditions
  - Fans operation and control
  - Hot water distribution
  - Tower performance
  - Pumps operation and control

# MEASUREMENTS AND INSTRUMENTATION

- Measurements are critical in any serious effort to conserve energy

- Purposes
  - Quantify energy consumption within the plant
  - Monitor equipment performance
  - Check equipment condition

- Examples of Measurements and Instrument types
  - Flow/Velocity : Orifice plate, Pitot tube, Venturi tube, Turbine meter, Vortex shedding flowmeter, Ultrasonic flowmeter
  - Temperature : Thermometers - Bimetallic, Resistance etc., Thermocouple, Radiation pyrometer
  - Pressure : Bourdon gauge, Diaphragm gauge, Manometers
  - Stack Gas Analysis : Orsat apparatus, Oxygen analysers, Carbon dioxide analysers, Carbon monoxide analysers
  - Heat Flow : Thermography equipment
  - Electrical : Multimeter, Ammeter, Wattmeter, Power factor meter, Light meter
  - Steam Trap Testing : Stethoscope, Ultrasonic detector

## ENERGY CONSERVATION MEASURES

## SHORT-TERM : 6 MONTHS TO 1 YEAR

- Good Housekeeping, e.g.
  - Prevention of obvious sources of leakage of oil, steam, compressed air, water etc.
  - Prevention of air infiltration into combustion equipment like boilers, furnaces etc.
  - Reduction in heat loss from steam pipes, bare hot surfaces, furnace walls etc. by better insulation practices
  - Better air-fuel ratio control
- Optimum loading of combustion equipment through proper production planning and control
- Recovery of process condensate
- Proper scheduling of electrical loads to limit maximum demand, achieve high load factor, and improve power factor
- Introduction of proper maintenance systems for boilers and furnaces
- Training of boiler and furnace operators

ENERGY SAVINGS : 10-30 PERCENT DEPENDING ON EXISTING LEVEL OF EFFICIENCY

RECOVERY OF INVESTMENT : LESS THAN 6 MONTHS

AMOUNT OF INVESTMENT : NEGLIGIBLE

## ENERGY CONSERVATION MEASURES

### MEDIUM-TERM : 2 TO 3 YEARS

- Waste heat recovery devices like air preheater, economiser etc.
- Instrumentation systems on boilers, furnaces and processes, including automatic control
- Variable speed drives for electric motors, energy efficient motors, automatic electrical load management control system, capacitors to improve power factor etc.
- Low-temperature heat recovery devices for central air-conditioning systems, process dryers etc.
- Replacement of existing oil burners by low-excess air burners, firebricks by ceramic fibre etc.
- Minor process modifications for greater efficiency

ENERGY SAVINGS : 10-20 PERCENT

RECOVERY OF INVESTMENT : 6 MONTHS TO 2 YEARS

AMOUNT OF INVESTMENT : MODERATE

## ENERGY CONSERVATION MEASURES

## LONG-TERM : 5 TO 10 YEARS

- Total energy systems
- Computers for process control and energy management on real-time basis
- First-order evaluation of technological developments in developed countries relevant to present practices leading to further techno-economic evaluation of attractive options
- Induction of latest technology based on these findings
- Total modernisation of management practices and technology of manufacture

ENERGY SAVINGS : 30-40 PERCENT

RECOVERY OF INVESTMENT : 3 TO 5 YEARS

AMOUNT OF INVESTMENT : SUBSTANTIAL (CAPITAL INTENSIVE)

Workshop on
Energy Management in Industrial Sector

November 24-26, 1986

## GROUP DISCUSSION

Group I : Technical Issues and Barriers in Energy Conservation in Industry

Group II: Economic Issues and Barriers in Energy Conservation in Industry

Group III: Policy Aspects and Incentives for Energy Conservation in Industry

| GROUP I | GROUP II | GROUP III |
|---|---|---|
| Mr. B.P. Agarwal | Mr. G.K. Bajaj | Mr. D.P. Chattopadhyay |
| Mr. H.S. Ajwani | Mr. B.K. Das | Mr. K.L. Chopra |
| Mr. V. Baskaran | Mr. Azizullah | Dr. S.K. Gangopadhyay |
| Mr. R. Chanda | Mr. B. Lakshminarayan | Mr. R.K. Gupta |
| Mr. Bedobrata Goswamy | Mr. B.K. Nag | Mr. K.S. Mukherjee |
| Mr. P.K. Kapil * | Mr. S.L. Palival | Dr. P.J. Nayak * |
| Mr. D. Prasad | Mr. S.R. Sen * | Mr. J.U. Pereira |
| Mr. G. Raghavendra | Mr. Gurcharan Singh | Mr. K.K. Rai |
| Mr. K.S. Rangan | Mr. Manoj Yadav | Mr. M.P. Sastry |
| Mr. Y. Singh | Mr. Gurmel Bhatwa | Mr. S. Barooa |
| Mr. Shauquat Alam | Mr. B.K. Mohapatra | Dr. L.P. Rai |
| Mr. A.K. Ghosh | | |

* Group Moderator

DR. R. K. PACHAURI
DIRECTOR

TATA ENERGY RESEARCH INSTITUTE
7, JOR BAGH NEW DELHI - 110003

**Dr. R.K. Pachauri, Director**
**and Staff of the**
**Tata Energy Research Institute**

request the pleasure of your company
at a
**RECEPTION**
on
Monday, the 24th November, 1986

to greet the participants
of the workshop on
Energy Management in Industrial Sector

Venue: 7 Jorbagh,
New Delhi - 110003

Time : 6.30 - 8.00 p.m.

**R.S.V.P.**
Regrets only:
Phone : 619205

# PLANT - LEVEL ENERGY MANAGEMENT

## Introduction:

The rising cost of energy in India over the past one and a half decades and its poor availability represents, for the industrial sector in particular, a major factor affecting its profitability and competitiveness. Plant level energy management is therefore a sound and sensible approach to adopt by industry as a step to realising economies in the use of energy. This could, in most cases, translate itself to 15-20% energy savings in the short and medium terms itself. The advantages are not solely in the pecuniary gains achieved but also in the areas of improved quality of products and the environment. It also affords an opportunity for various departments to work in a multidisciplinary way that is quite different from the traditional manner that industrial production entails.

The primary use for energy is to provide process heat and cold, drive equipments and machinery, lighting and transport. These end users employ a myriad of processes and present several energy conservation opportunities through interventions of a management and technical kind. These 'interventions' represent decisions and actions that owe their origin to studies and analysis conducted at the plant.

## Types of plant energy studies:

Energy cannot be saved until it is known where and how it is being used. In most cases, the establishment of this baseline requires a comprehensive and detailed survey of energy uses and losses; this survey is referred to as the energy audit. Plant energy studies can be carried out in two sequential phases: the Preliminary Energy Audit (PEA) and the Detailed Energy Audit (DEA). Having conducted an energy audit does not, however, constitute in itself an energy

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The veiws expressed are those of the author and not that necessarily of USAID.

conservation program. A number of other conditions must also be met. First, there must be a will to save energy. Second, viable project must be evaluated according to the company's financial guidelines. Third, financing must be available, and fourth, plant management and staff must be committed to continuing the energy rationalization effort well beyond project implementation, as the benefits of good projects can be lost as quickly as they are gained. Table 1 lists out some of the basic requirements for a successful Plant energy management program.

## Energy Audit Concepts:

It would be important to define the term **energy audit** at this stage. Although we have been using this term for the past few years an acceptable definition is yet to emerge. While some consider it as a financial term or statement in respect of energy consumption, others use it as a diagonistic tool for evaluation of energy consumption and strategic planning for conservation. The term was first used in USA in 1977 in connection with the Supplemental State Energy Consumption Program (S.S.E.P.). This was basically for determining mimimum eligiblity requirement for financial assistance from the state to industry, hospitals, hotels, etc. In some countries like Japan, Taiwan and South Korea this has become a legal requirement like financial audit. The following definition can serve our purpose:

> "The energy audit serves to identify all of the energy streams in a facility and quantifies energy use according to discrete functions. It serves the purpose of identifying where and why a facility uses energy and identifies energy conservation opportunities."

As mentioned earlier energy audit can be carried out in two sequential phases: the PEA and the DEA. The PEA is essentially a preliminary data gathering and analysis effort. It consists of two parts: the energy managament audit through which the auditor becomes acquainted with investment decision criteria referencing energy conservation projects, and the technical energy audit. The technical part of the PEA uses only available data and is compeleted without sophisticated instrumentation. The PEA is conducted in a very short time frame and relies heavily on the auditors experience. It focusses on obvious areas of improvement in energy savings such as steam leaks, compressed air leaks, poor insulation, inoperative instrumentation, operational deficiencies of combustion equipment, idling machinery, and so forth. The typical output of a PEA is a set of recommendations on immediate low-cost actions that can be taken and, usually, a recommendation for a Detailed Energy Audit (DEA). Table (2) outlines the steps required for conducting a PEA.

The DEA which must be conducted after a PEA, is an instrumented survey followed by a detailed plant energy analysis. Sophisticated insturments are used to enable the energy auditor to compute energy efficiencies and energy balances during typical equipment operation. The instruments commonly used are flow meters, combustion gas analyzers , psychrometers, heat loss meters, etc. The actual tests performed depend on the type of facility under investigation and the objective, scope and level of funding of the energy management program. Hence a DEA could take as little as 1 man-week or as much as several man-years in a sophisticated refinery or fertilizer plants.

## Data Compilation

Typical forms can be designed to collect data on consumption and costs of energy. Some of these forms are shown in Exhibits 1 through 4. These forms obviously cannot be used for every industry. In addition, they do not show the interaction between energy-using systems (for example between the boiler, steam network and the steam consuming system).

In most of the energy audit programs maximum difficulty is experienced in data collection due to:

- Inadequate instrumentation (for example even where steam flow meter is available, pressure and temperature at the same point may not be available;
- Historical data not available;
- Poor accessibility to equipment; and
- Plant operational and design data unavailable.

## Energy efficiency determination

The efficiency of energy use has two different, although not separate, components - technical efficiency and economic energy efficiency.

The first component, technical efficiency, is often measured by the first law of thermodynamics, which provides a quantitative estimate of the ratio of useful heat output to energy input. The technical efficiency can also be evaluated by the second law of thermodynamics which considers quality of energy and is often preferred when value judgements in energy efficiency must be made. Efficiency under the second law is defined as the ratio of the least amount of energy necessary to achieve a particular objective to the anount of energy actually used to attain this objective. Because second law computation is a rather complex exercise, it is seldom required for the typical energy user and the technical efficiency according to the first law is of more practical importance today. The second component, economic energy efficiency is not that well defined a concept in absolute terms. Rather, one refers to relative economic energy efficiency when an energy related decision such as fuel substitution in a furnace or cogeneration in a plant results in providing the same energy service at a lower cost.

**Actions to improve the technical energy efficiency would require:**

i. Experimental investigations to draw up energy balances of equipments and processes.

ii. Following (i), developing operational procedures in the following areas:

    a. Improved design and construction
    b. Maintenance

Let us take the example of a drier and examine briefly some of the areas that an energy auditor should address.

The thermal efficiency of a drier may be expressed as,

$$\text{efficiency} = \frac{\text{Heat required to evaporate fluid from material}}{\text{Fuel imput}}$$

In drying operation, heat must be supplied to:

- Heat the incoming air
- Warm the material being handled
- Heat up the water in the incoming material and evaporate it
- Make up for the heat losses by conduction, convection, and radiation

The drier efficiency is determined by completing an energy or heat balance of the drier. Conducting a drier heat balance involves measuring a number of items as well as knowing certain properties of the material being dried. Information required includes:

a. Material moisture content before and after drier.

b. Fresh air dry bulb/wet bulb temp.

c. Exhaust air dry bulb/wet bulb temp.

d. Heat (steam) supplied to heat fresh air

e. Air flow rate

f. Material specific heat

g. Material through-put

Using the above information and psychometric charts it is possible to balance mass and energy flow through the drier. Checklists have also to be prepared in order that certain house-keeping and maintenance procedures are followed.

## The Energy Management Structure

The intensiveness of energy usage by industry is a useful indicator of the need and type of energy management structure that may be devised. Some of the major energy intensive industries are -

(1) Steel plants (primary steel plants, mini-steel plants, integrated steel plants)

(2) Metallurgical (foundry, forging, aluminimum, copper, etc.,)

(3) Chemicals (organic, inorganic, petrochemicals, chloralkali)

(4) Others (cement, refractories, ceramic, glass textile, etc.)

All the forms of enterprises mentioned above can be associated with different levels of energy consumption from high energy consuming industries (e.g. steel, aluminimum) to lower energy consuming industries (textile, tea). It is indisputable that energy management activities should be present in all of these enterprises with varying degrees of effort and concentration depending mainly upon the scope for energy productivity gains. The energy management activities for the most part would be common to all the enterprises in terms of the nature of the conservation actions initiated. Generally, the common measures, also known as horizontal approach to energy conservation account for almost 60 to 70% of the potential energy savings in a plant. Conservation measures peculiar to a particular industry and process known as the vertical approach towards energy management account for the remainder. Thus the Energy Management structure activities should be responsive to both these approaches.

As a consequence of what has been discussed above, industry should provide for an energy management structure. Fundamentally, this means that the personnel involved in energy management should be empowered with the necessary authority in order to pursue their fundamental tasks related to:

(1) Planning

(2) Execution, and

(3) Control, in the management of energy.

They should be associated with the nodal points of the policy planning and production activities of the enterprises at all levels.

The Energy Management Structure may change depending upon the particular characteristics of the industry, its internal organization, its size and objective and even its geographical location. In a very large industrial plant which has several production plants, the energy management structure would necessarily have to be embodied in several departments and offices in one or more locations of its territory. In these circumstances, an Energy Manager at the top level will be the head of the department of Energy Management with its own staff and will coordinate the energy managers of the various plants the the lower levels. An Organization Structure illustrating this case is given in Exhibit 5.

Enterprises of intermediate size may require a full time Energy Manager at the top level with possibly a suitable staff of full time or part time energy management personnel. The staff could be drawn from various departments and top management could form a committee of production heads to oversee the activities related to energy management. The committee approach has several advantages in that it draws upon the inherent talents within the enterprise and allows for a more democratic manner of functioning. An organization structure illustrating this case is given in Exhibit 6.

In small enterprises, it may not be necessary to have an Energy Manager at all. Rather, the duty could be performed by a senior staff member with the assistance of a few junior engineers. An organization structure illustrating this case is given in Exhibit 7.

In all the above cases, it is extremenly important that the functional head of the Energy Management group has access to the top management. Hiarchially each energy man (Personnel in the E.M. group) should be sub-ordinate to the energy manger of his plant, whereas the energy manager is autonomous within the organization, between those responsible for generation and distribution of energy and those responsible for its use. It is also important that the energy management group has within it a wide spectrum of exprience and knowledge ranging from financial competence to technical and maintenance knowhow. The options and suggestions of consultants or of consulting agencies might be of use to enterprises of all types. They can prove to be an important aid to the management of energy in an enterprise.

The energy management structure may vary in terms of its functions in existing industries as against in a projected new industry. Broadly speaking, in existing industry, energy management and conservation is achieved through:

(1) Proper procedures in operation and maintenance

(2) A continuous evaluation of energy conservation opportunities

In the above the 'control activity' is largely emphasised.

In a projected new industry, the energy management unit should provide the top management with its analysis of:

(1) The equipments and processes to be installed

(2) The input - output fluxes of energy forms

(3) The scope for process integration, redesign and nature of production runs.

In the above case, largely the 'planning activity' is emphasised. The planning and control activities as separate components can be further understood by the following simple example in a existing plant:

**Example:** In an industry where boilers are installed to meet the process steam requirements, the average efficiency was around 70%. Although at that time when the project was developed 70% was a good figure, in the present stage of technology and higher energy costs, an increased efficiency is both desirable and obtainable.

The Energy Management Approach could involve two case alternatives:

Case 1: **Where the residual amortization of equipment (boilers) is relatively higher than the fuel and maintenance costs**

In the above case particular attention is to be paid to the achievement of targeted or design performances, even if they are not the best in terms of the present state of technology and high energy costs. Thus the 'control activity' is emphasised.

Case 2: **Where the residual amortization of the boilers is relatively low compared to the maintenance and fuel costs**

In this case, a new design of the total thermal generation and utilization areas has to be carried out. New high performance boilers may have an efficiency ranging around 90%. In addition, the possibility of co-generation could be examined. These opportunities should induce the energy management group to suggest the installation of new utilities. Here, the 'planning activity' is emphasies.

The control activities would be a routine job for the Energy Management group. An occasional activity would be the development of norms, targets and goals of energy consumption through the application of energy audits. The specialized activity would be the planning intervention involving major energy project developments.

The activities hitherto explained are an inherent feature of the functions of the energy manager.

**The Function of the Energy Manager:**

The functions of the energy manager can be broadly classified as:

(1) The Technical Function
(2) The Managerial Function

It may be mentioned that the above two components in actual practice cannot be isolated and the duties of the Energy Manager generally involves both of them. The technical function largely relates to the management of thermal energy equipments/processes and electrical energy equipments/processes. The energy management of thermal and electrical equipments are related to and depend upon the several kinds of energy using devices encountered in industrial energy management. Some of the are -

| Thermal equipments | Electrical equipments |
|---|---|
| Burners | Motors |
| Boilers | Fans |
| Furnaces | Compressors |
| Driers | Pumps |
| etc. | etc. |

The technical function of the energy manager is essentially to improve the technical efficiency of the thermal or electrical equipment. The concept of technical efficiency has been touched upon earlier.

The managerial functions of an energy manager may change with the size and the type of the organization. But, they should include some or all of the following:

(a) To develop an Energy Accounting System

(b) To coordinate the effort of energy users

(c) To give technical advice on the energy saving equipments and procedures

(d) To identify possible energy conservation opportunities

(e) To train energy users and stimulate interest in energy conservation

(f) To plan and participate in Energy Audits

(g) To survey and review the literature on energy developments and properly disseminate this information

(h) To make plans for energy emergency or cut-backs.

**Organizing for Energy Management Data Base:**

If the energy Manager is to fulfil these functions, an Energy Data Base is an essential prerequisite. Record keeping, energy accounting systems and surveys within the company in the fashion of an energy audit provide the data base for any Energy Management program. A corollary to this is that the energy manager must be given access to all information related to the energy flow in the industry. Development of an energy data base is a continuous task and the planning and conduct of energy audits is perhaps the initial step. It may not be necessary for the energy manager or his team to conduct the energy audits. Rather, the work could be left to a core-group of engineers within the plant or the asssitance of a consultancy agency may be sought. It is to be mentioned that energy audits are merely an aid to optimising energy usage and not an end by itself. It is important to reiterate certain important guidelines regarding the procedure for energy audit as well as the means for identification of energy saving opportunities.

**Energy Accounting:**

Particular records related to energy consumption should be kept. They are:

(1) The cost evaluation of different forms of energy

(2) Energy consumptions strictly connected to the process (e.g. electricity in electric arc furnaces, steam consumption in a stenter, etc.)

(3) Energy consumption related to utilities (e.g. electricity consumption for water pumps, air compressors, refrigeration compressors, etc.

(4) Energy consumption related to general services such as for lighting.

(5) Energy consumption related to comfort conditions i.e. electricity for HVAC systems, etc.

It is important to realize that energy accounting or record keeping are required not only as a consequence of energy audits during the initial stages of the planning phase but also after the energy saving strategies have been applied during the control phase.

The monitoring of energy consumption should be continuous and the records of accounting systems uniform and maintained in consistent units. Deviations in energy consumptions must be carefully analyzed and explanations sought. Careful monitoring over a period of time would help the energy manager to understand his equipments better.

**Identification of Energy Conservation Opportunities:**

Energy saving opportunities within an industry fall under the following three categories:

(1) as a consequence of deterioration in equipment performance over time

(2) As a consequence of up-gradation of technology

(3) As a consequnce of changed plans for the production of goods or services.

Where an energy conservation opportunity presents itself, it falls under either of the two categories:

(1) As a result of house-keeping measures, which generally involves little or no capital investment. In this circumstance, the energy manager should promptly take necessary action.

(2) In the second case, the conservation opportunity involves an investment in equipment redesign or retrofit. In the case the energy management structure in the enterprise must involve itself in a feasibility study based on the data base established through detailed energy audits.

Finally, a point may be made on the readability of the energy reports which an energy manager would have to issue from time to time. The energy report has to cope itself with different demands for readability. For instance, an engineer in a production department would be interested only in the energy consumption relevant to his product.

The Purchasing manager may be interested only in the evolution of the energy prices, whereas the the General Manager in the same factory would be interested both in energy consumption per unit of product as well as energy prices since he is responsible for overall costs and efficiency. Several times it has been noted in industry that energy reports have not been carefully compiled to meet the demands of various users in the plant.

**Conclusion:**

While the need for energy conservation has been well recognized in Indian industry, the Energy Manager has not yet been preceived to play a distinct role in company affairs. It is observed that in industries where cost of energy has a crucial impact on the cost of production and profitability, their response to higher energy costs is often limited by the lack of an institutionalized energy management structure to apply the technical options that are available for reducing their energy costs. These technical options require planning and control interventions of a specialized nature.

It may not always be possible for the existing functional departments in industry to take upon itself the responsibility of management of energy.

The paper while discussing the objectives and features of energy auditing, focussed the need to develop an Energy Management structure in industry and outlined the expected functions of the energy manager. It is hoped that the views presented would provide industry with some guidelines in its task of establishing Plant Energy Management programs.

Note: The author would like to record his appreciation to Ms. Jasvinder Kaur for her assistance in typing and editing the manuscript.

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iii. The Emerging Role of the Energy Manager - S. Padmanabhan, paper presented at National Energy Mgt. Conference, organized by PCRA, March 1985 at Madras.

iv. Industrial Energy Auditing Manual - prepared for USAID by Hagler, Bailly and Company, USA and Reliance Energy Services, USA.

## Table 1

Basic requirements for successful plant energy management program

- Commitment at Corporate Level to Energy Conservation
    - Resources, personnel, funds

- Optimum use of resources
    - Intercompany information system
    - Centralized technical support
    - Facilities management training

- Identification of opportunities
    - Quick payback items
    - Capital intensive projects
    - Evaluation and relationship to production

- Implementation of projects
    - Self-financing
    - Capital project selection
    - Specification and bid

- Establishment of operational criteria
    - Optimum production/energy targets
    - Operations and maintenance procedures

- Monitoring and Targets
    - Evaluation
    - Re-evaluation

## Table 2

Steps in conducting a preliminary energy audit.

1. Organize resources
   - Manpower/time frame
   - Instrumentation

2. Identify data requirements
   - Data forms

3. Collect data
   - Conduct informal interviews
   - Conduct plant walk-through

4. Analyze data

5. Develop action plan
   - Immediate conservation actions
   - Projects for further study
   - Resources for detailing energy audit
   - Refinement of energy management program.

| TYPE OF ENERGY | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| YEAR | FUEL | | | | | | | | | | | | ELECTRICITY | | | | | | | Total Kcal | Total Cost |
| | FURNACE OIL | | | | | | COAL | | | | | | | | | | | | | | |
| | MT (1) | Rs / MT (2) | Rs (3) | Rs / Kcal (4) | % of Total Kcal (5) | % of Total Cost (6) | MT (1) | Rs / MT (2) | Rs (3) | Rs / Kcal (4) | % of Total Kcal (5) | % of Total Cost (6) | KWH (1) | Rs / Kwh (2) | Rs (3) | Equi Kcal (4) | Rs / Kcal (5) | % of Total Kcal (6) | % of Total Cost (7) | | |
| 1978 | | | | | | | | | | | | | | | | | | | | | |
| 1979 | | | | | | | | | | | | | | | | | | | | | |
| 1980 | | | | | | | | | | | | | | | | | | | | | |
| 1981 | | | | | | | | | | | | | | | | | | | | | |
| 1982 | | | | | | | | | | | | | | | | | | | | | |
| 1983 | | | | | | | | | | | | | | | | | | | | | |

**Exhibit 1**

# PRODUCTION FIGURES

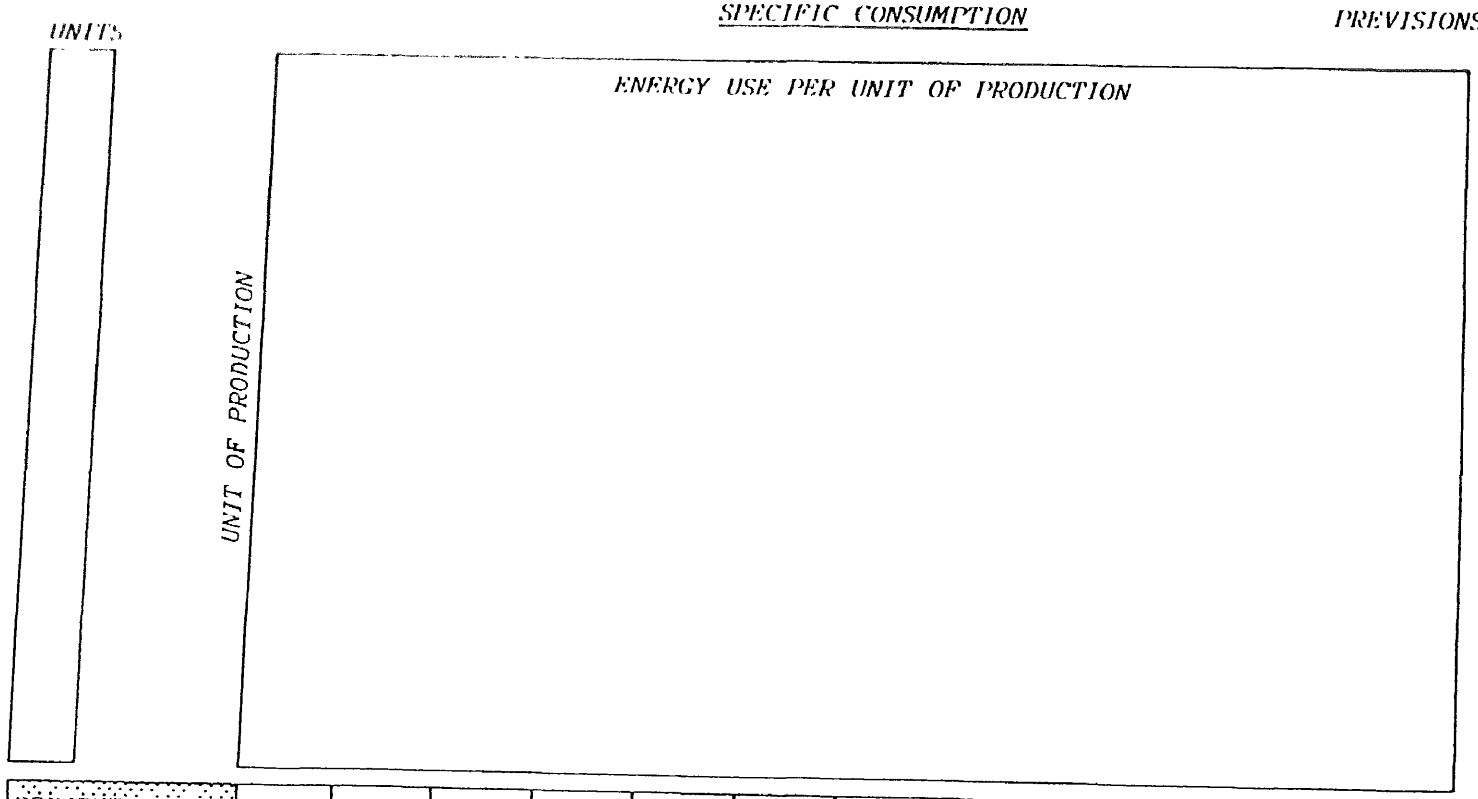
| Year | Production, Tonnes | Total Energy consumed, . Kcal | Specific Energy consumption of finished product, Kcal/Tonne |
|---|---|---|---|
| 1978 | | | |
| 1979 | | | |
| 1980 | | | |
| 1981 | | | |
| 1982 | | | |
| 1983 | | | |

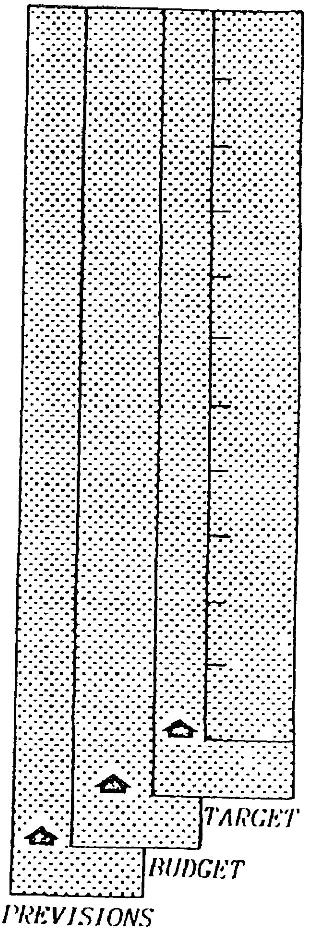
**Exhibit 2**

FACTORY . . . . Dpt . . . . . . . . . . . .

PRESENT STATE ▬▬▬
BUDGET ▬ ▬ ▬
LAST YEAR STATE ┅┅┅
PREVISIONS ▬ · ▬ ·

## SPECIFIC CONSUMPTION





| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| PRESENT STATE | | | | | | | | | | | | |
| BUDGET | | | | | | | | | | | | |
| LAST YEAR STATE | | | | | | | | | | | | |
| VAR. CUM. | | | | | | | | | | | | |
| MONTHS | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC |

Exhibit 3

# *TABLE FOR THE INVENTORY OF THE EQUIPMENT CONSUMING ELECTRICAL ENERGY*

*INVENTORY OF ENERGY USING EQUIPMENT*
*PLANT:* ______________________
*ADRESS:* ______________________

*TYPE OF ENERGY USED: ELECTRICITY*
*DEPARTMENT:* ______________________
*DATE:* ______________________

| *Equipment descript.* a | *Fonction* b | *Inventory number* c | *Location* d | *Elec. cons. per unit KW* e | *Number of units* f | *Total elec. consumption KW* g | *Operating hours per* h | *Elec. cost per hour* i | *Elec. cost per year* l | *Comments* m |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | |
| | | | | | | | | | | |
| | | | | | | | | | | |
| | | | | | | | | | | |
| | | | | | | | | | | |
| | | | | | | | | | | |
| | | | | | | | | | | |
| | | | | | | | *Total annual Energy cost* | | | |

*column g - exf* *column l = h x i*

**Exhibit 4**

## ORGANISATION CHART OF A LARGE ENTERPRISE WITH TWO PRODUCTION PLANTS

(Arrows indicate as to whom the Energy Manager could report to)

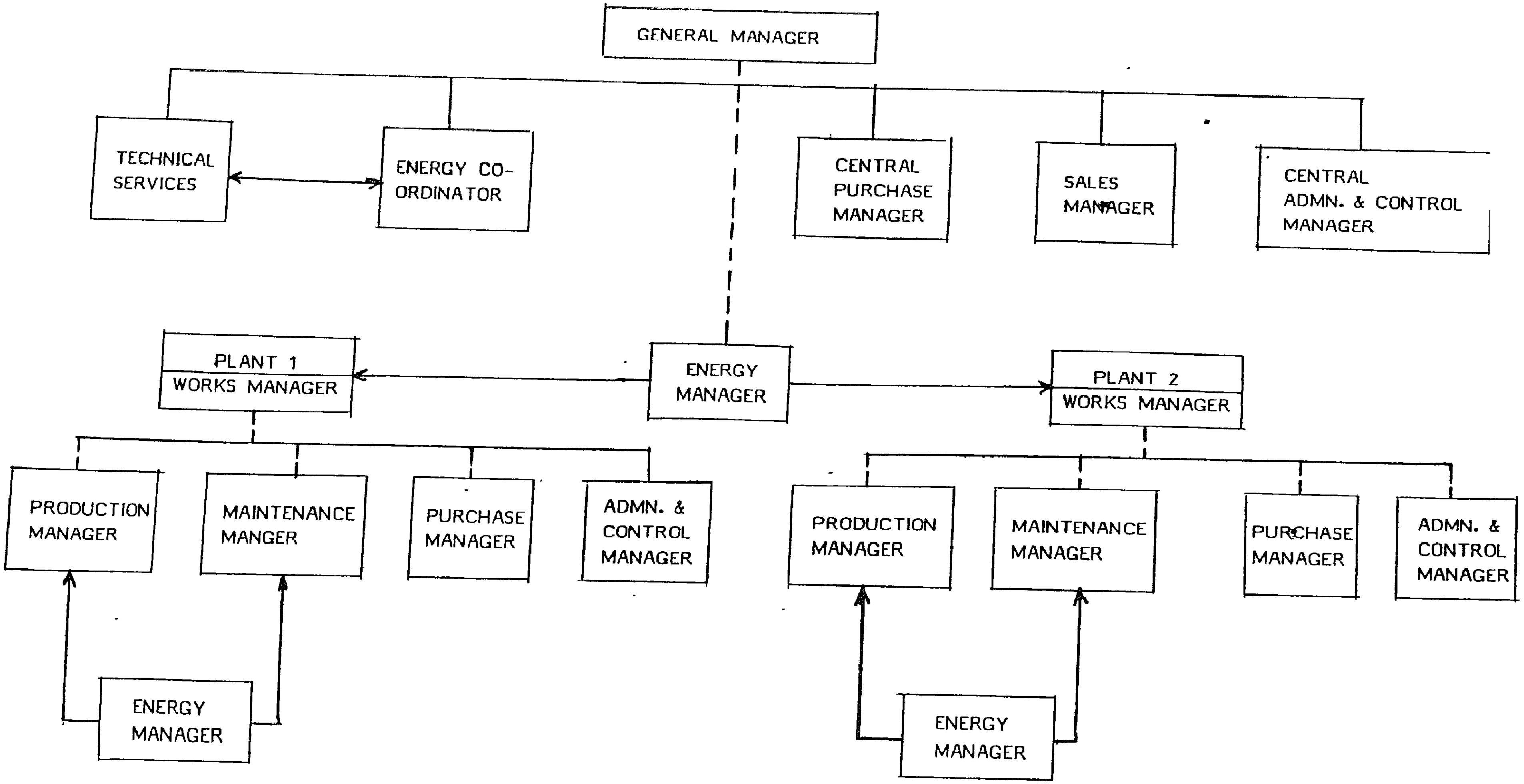


**Exhibit 5**

# ORGANISATIONAL CHART OF A MEDIUM SIZE INDUSTRY

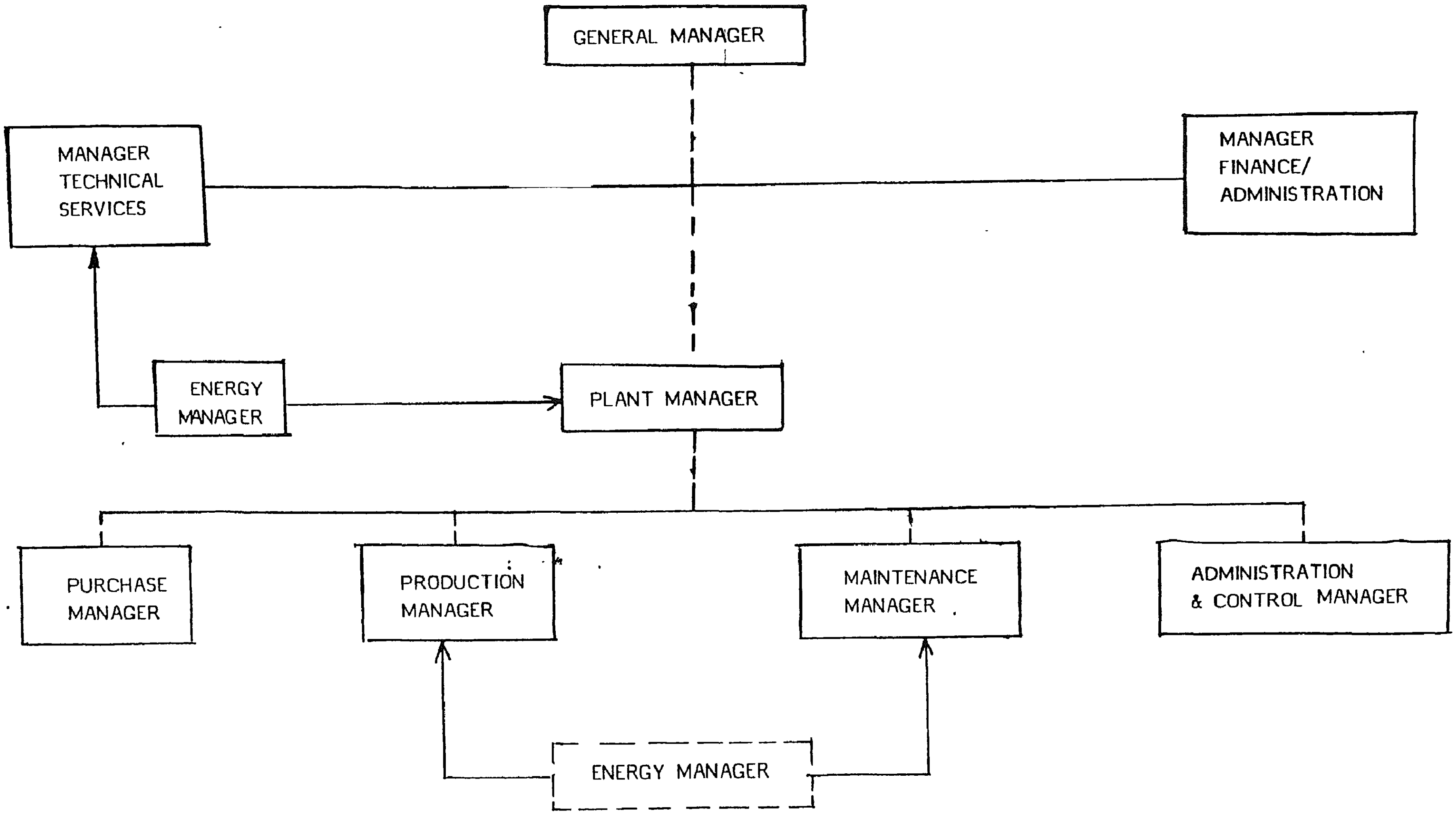


**Exhibit 6**

## ORGANISATION CHART OF A SMALL INDUSTRY

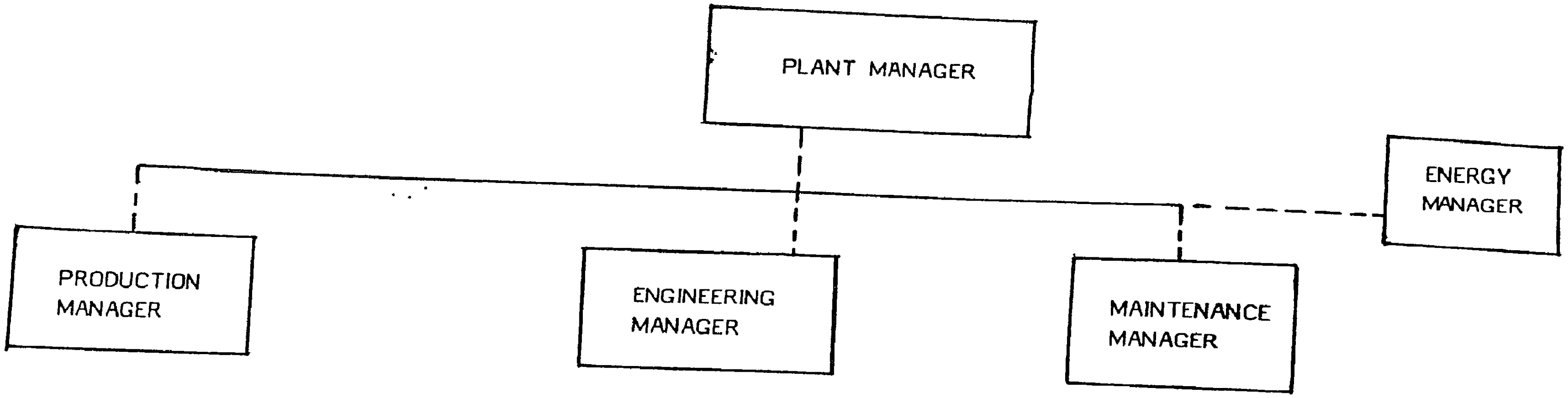


**Exhibit 7**

# ENERGY CONSERVATION IN PETROLEUM REFINING INDUSTRY

## OPPORTUNITIES AND ACHIEVEMENTS

# ENERGY UTILIZATION PROFILE

(INPUT IN EQUIVALENT FUEL TONNES/DAY)

| | NEW UNIT | OLD UNIT | OLD UNIT WITH CONSERVATION |
|---|---|---|---|
| FUEL | 224·2 | 352·5 | 328·7 |
| STEAM | 56·2 | 23·9 | 27·3 |
| POWER | 29·5 | 24·2 | 34·8 |
| TOTAL | 309·9 | 400·6 | 390·8 |
| (% ON CRUDE) | 1·78 | 2·35 | 2·21 |

FIGURES GIVEN ABOVE ARE FOR CRUDE/VACUUM UNIT.

TYPICAL PROFILE FOR OVERALL REFINERY

| | A | B |
|---|---|---|
| FUEL | 60% | 56% |
| POWER | 12% | 5% |
| STEAM | 28% | 37% |
| REACTION HEAT & OTHER FUELS | | 2% |

FUEL IS THE LARGEST CHUNK OF ENERGY INPUT

# ENERGY CONSERVATION OPTIONS INCLUDE

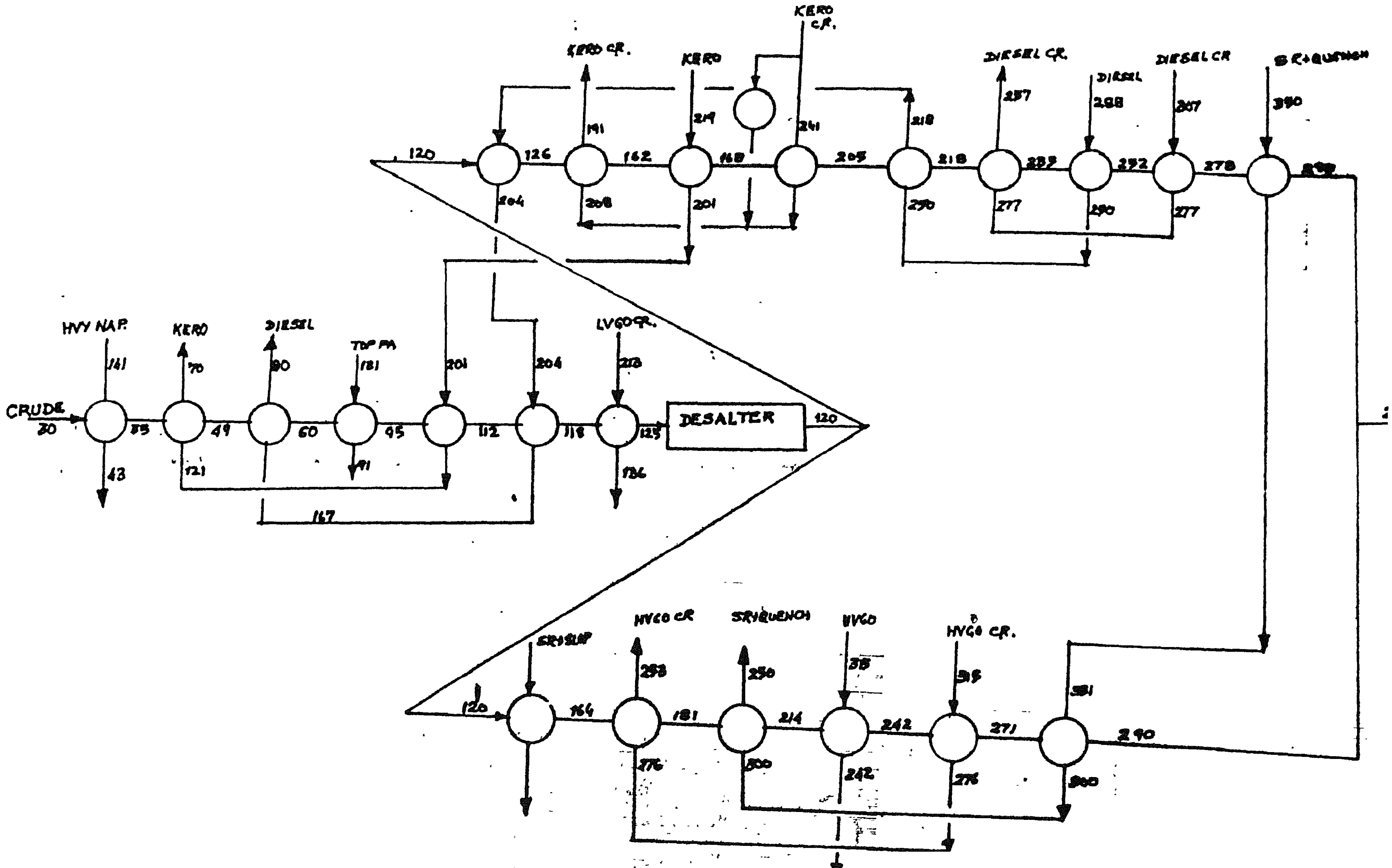
- INCREASED CRUDE PREHEAT
- INTEGRATION & MAXIMISATION OF LOW LEVEL HEAT RECOVERY
- ADDITION & MODIFICATION OF EQUIPMENT
- CHANGES IN PROCESS PARAMETERS
- CHANGES IN TECHNOLOGY
- COGENERATION
- FLARE GAS RECOVERY
- GOOD HOUSEKEEPING

ENERGY CONSERVATION SCHEMES SHOULD AIM FOR...

- MINIMISING FUEL CONSUMPTION
- MINIMISING HEAT LOSS TO COOLERS

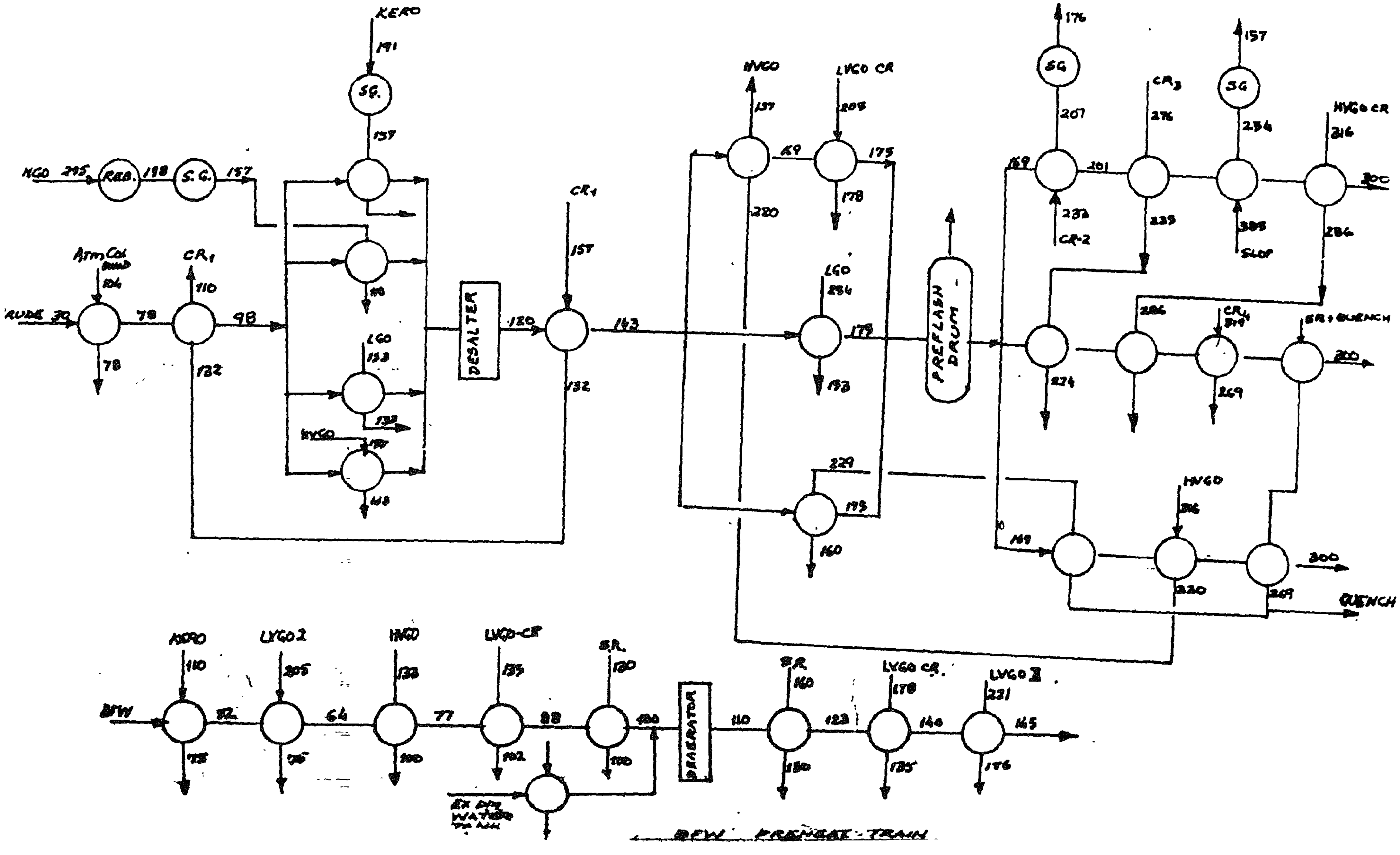
TYPICAL BENEFITS

- EACH 10°C PREHEAT IN A 6 MMT/YR REFINERY SAVES ~ 3500 - 4000 MT/YR OF FUEL.
- PREHEATING 100 MT/HR OF BFW TO 140°C SAVES ~ 10 000 T/YR OF FUEL.



CRUDE PREHEAT SCHEME

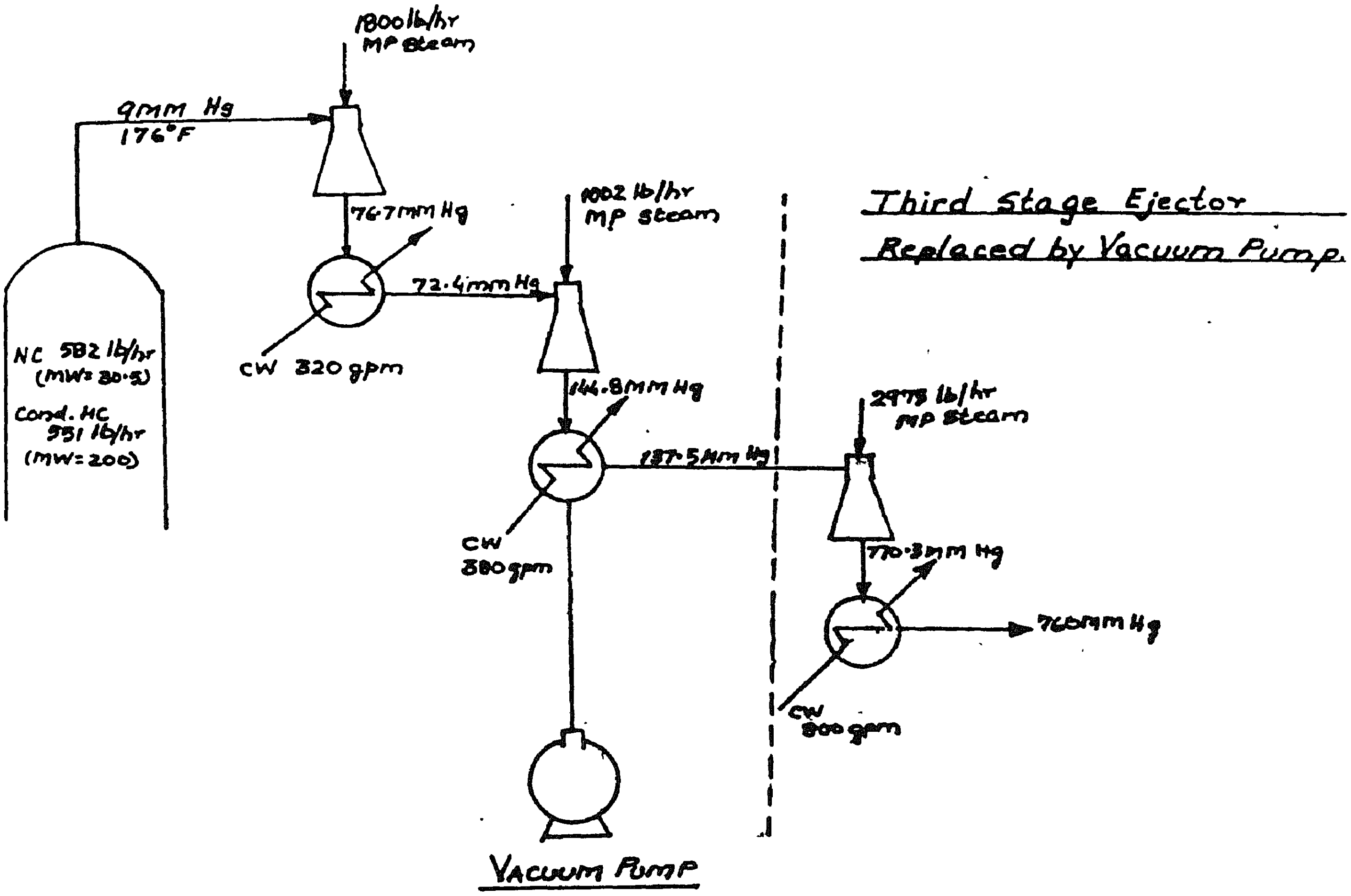
## CRUDE PREHEAT TRAIN



BFW PREHEAT TRAIN

# MODIFICATION/ADDITION OF EQUIPMENT FOR IMPROVED THERMAL EFFICIENCY,

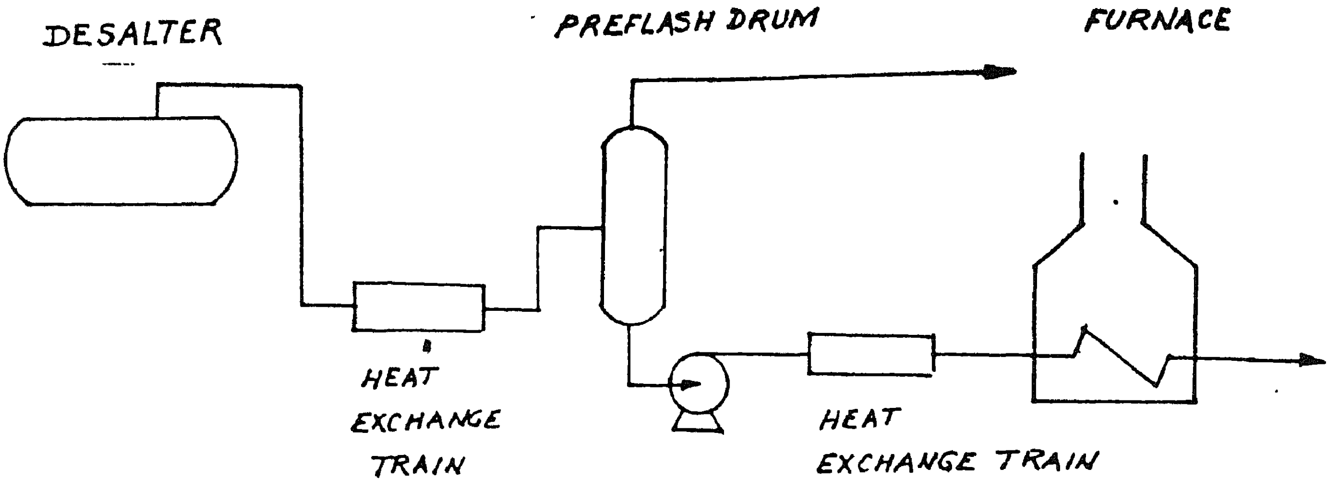
- ADDITION OF AIR PREHEATERS.
- USE OF PREFLASH DRUM
- USE OF VACUUM PUMPS
- USE OF EFFICIENT TOWER INTERNALS



| | | |
|---|---|---|
| )DGETARY COST OF PUMP & MOTOR | | $ 60,000 |
| | III STAGE EJECTOR | $ 19000 |
| 'ERATING COST OF VACUUMP PUMP | | $ 55648 /YEAR |
| | III STAGE EJECTOR | $ 236918 /YEAR |

## )SE OF VACUUM PUMP IN PLACE OF III STAGE EJECTOR

# USE OF A PREFLASH DRUM



| | A | B |
|---|---|---|
| CRUDE PREHEAT TEMP °C | 285 | 285 |
| PREFLASH DRUM PRES. ($KG/cm^2A$) | - | 4.5 |
| PREFLASH DRUM TEMP °C | - | 190 |
| % FEED FLASHED | - | 7 |
| HEATER OUTLET TEMP °C | 382 | 386 |
| HEATER DUTY KCALS/HR | $79 \times 10^6$ | $72 \times 10^6$ |

A FLOW SCHEME WITHOUT FLASH DRUM

B FLOW SCHEME WITH FLASH DRUM

FEED CONSIDERED 6 MMT/A B.H. CRUDE

## IMPROVING INTERNALS OF VACUUM TOWERS

- Use of packings instead of trays in vacuum towers gives lesser pressure drop, thereby reducing FZ temperature. Lower FZ temperature reduces heater duty and results in energy savings.

- A Case Study

  1.7 MMtpa FPUs in wet vacuum operation

| **Particulars** | MRP | GRSP |
|---|---|---|
| Tower Internals | Trays | Packings |
| Pressure Drop, mmWg | 70 | 28 |
| FZ Temperature, °C | 380 | 363 |
| Saving on Heater Duty |  |  |
| MMkcal/hr |  | 2.25 |
| Annual saving US $ |  | $0.35 \times 10^6$ |

- Additional Bonus
  - — Reduced tendency for cracking
  - — Increased capacity

# CHANGES IN TECHNOLOGY / PROCESS VARIABLES

- USE OF DRY VACUUM TECHNOLOGY IN PLACE OF WET VACUUM
- USE OF LOWER S/F RATIOS IN EXTRACTION PROCESSES.
- USE OF MULTIPLE EFFECT EVAPORATION

# USE OF DRY VACUUM IN VACUUM DISTILLATION

- Application

  Vaccum units for non-lube use

- A Case Study

  A 1.29 MMTPAFPU at Vizag

| Particulars | GRSP | VREP |
|---|---|---|
| Capacity MMTPA | 1.675 | 1.29 |
| Operation | Wet vacuum | Dry vacuum |
| Pressure at FZ, mmHg,'a'. | 112 | 24 |
| Coil+stripping steam, t/hr | 21 | NIL |
| Ejector Motive steam, t/hr | 3 | 11.7 (9) |
| Net saving of steam, t/hr | — | 12.3 |
| Annual savings US $ | — | $2 \times 10^6$ |

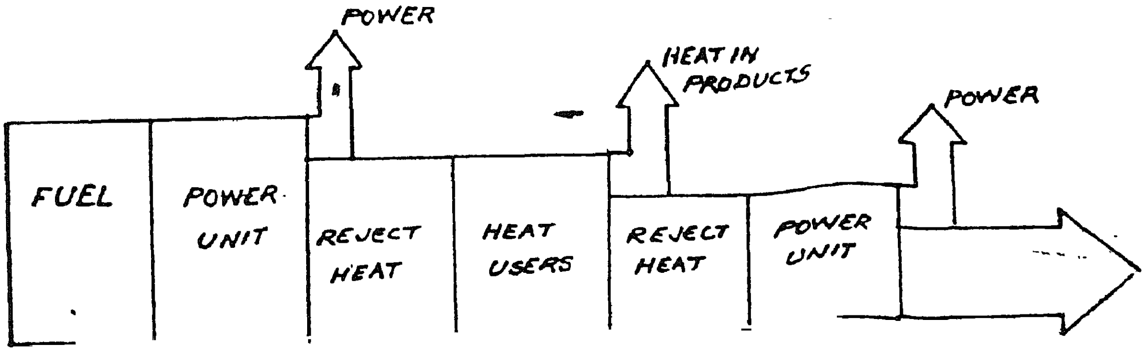
# EFFECT OF REDUCTION IN S/F RATIO
# ( FURFURAL EXTRACTION )

## OPERATING CONDITIONS :

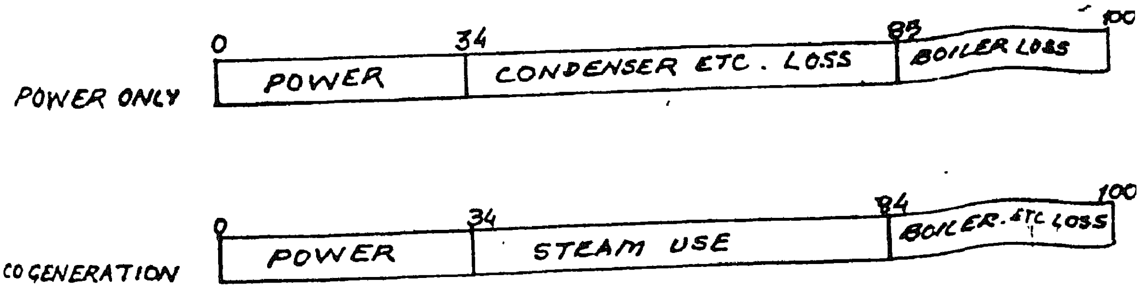
| | DESIGN | REVAMP (PROPOSED) |
|---|---|---|
| UNIT T'PUT MT/HR | 37.3 | 59.5 |
| S/F (V/V) | 2.98 | 2.1 |
| RAFFINATE YIELD (VOL%) | 65.7 | 68.0 |
| EXTRACTOR TEMP °C | 130/90 | 129/79 |

| UTILITY CONSUMPTION | | AVG. DESIGN | AVG. REVAMP |
|---|---|---|---|
| COOLING WATER | $M^3$/bbl | 5.51 | 2.5 |
| FUEL FIRED | Kg/bbl | 5.55 | 3.48 |
| MP STEAM | Kg/bbl | 8.96 | 2.64 |
| LP STEAM | Kg/bbl | 0.24 | 6.24 |
| POWER | Kwh/bbl | 1.78 | 1.03 |
| TOTAL ENERGY EQUIVALENT | MM CAL/bbl | 65.85 | 36.9 |

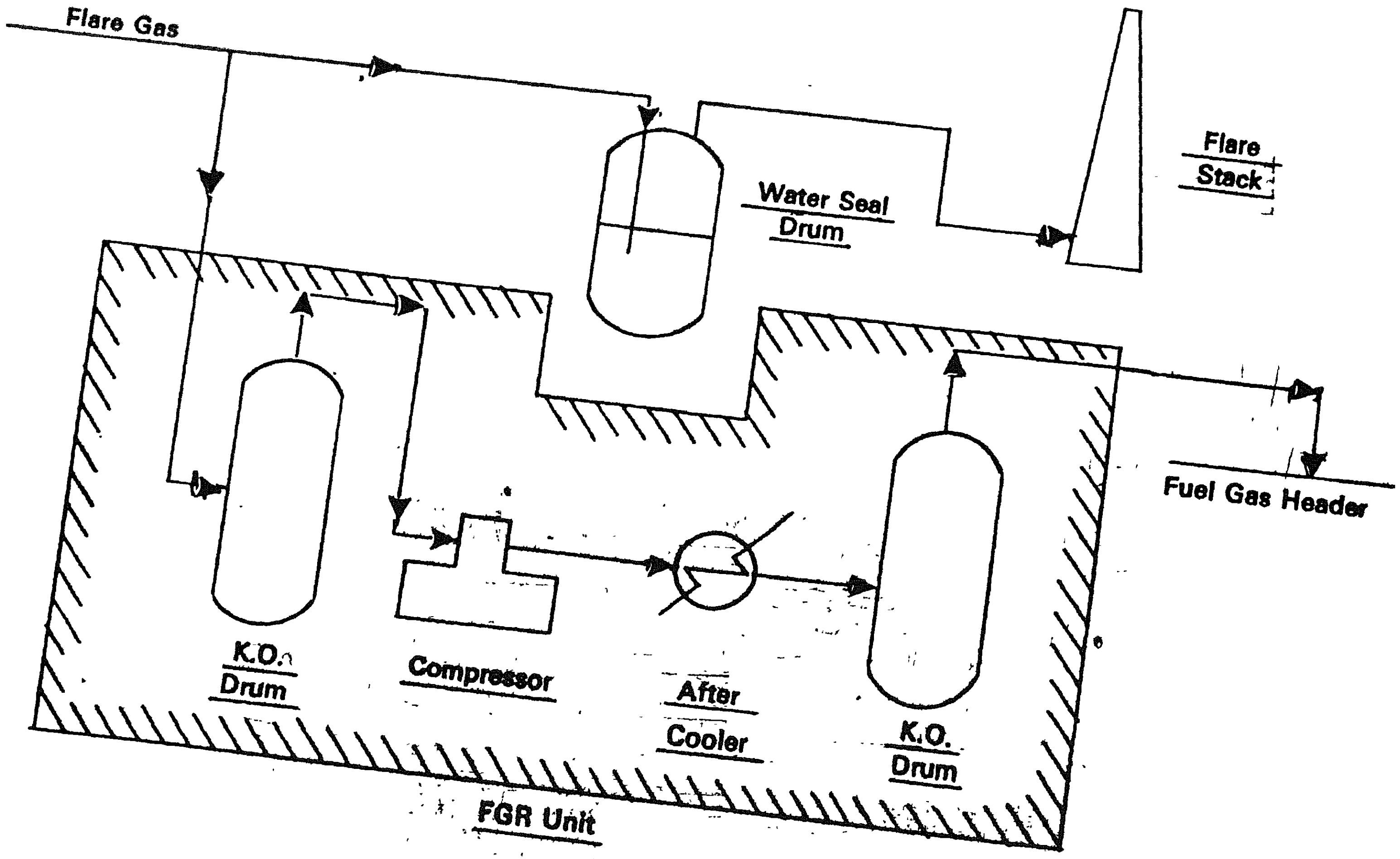
# CO - GENERATION



COMPARE : TPS



# WHAT IS FGRU


Flare Gas
Water Seal Drum
Flare Stack
Fuel Gas Header
K.O. Drum
Compressor
After Cooler
K.O. Drum
FGR Unit

# FLARE GAS RECOVERY

- **Objectives**
  - — Energy Saving
  - — Pollution Control

- **A Case Study**

A large Petrochemical complex in India

| | |
|---|---|
| Flare Gas Losses, t/hr | 2 |

Flare gas recovery system recovers all these losses as fuel gas to be used in the complex

| | |
|---|---|
| Equivalent Fuel oil saved t/hr | 2.8 |
| Annual savings US $ | $4.5 \times 10^6$ |
| Payout Period | Less than one year |

## FUTURE OPTIONS

- USE OF TEMPERED WATER LOOP TO PREHEAT BFW
- INTEGRATION OF PROCESS UNITS & TPS
- SWITCHOVER TO ELECTRIC TRACING
- USE OF LOW PRESSURE INST AIR SYSTEM
- HIGHER COOLING WATER TEMP. RISE.
- ANTIFOULANTS FOR IMPROVED HX PERFORMANCE
- ADVANCED COMPUTER CONTROL
- FLARE GAS RECOVERY
- RECOVERY OF VAPOURS FROM TANK VENTS/LOADING GANTRIES.

# ENERGY CONSERVATION IN REFINERIES

MAX POTENTIAL IN

- HEAT EXCHANGER TRAIN OPTIMISATION
- EFFICIENCY IMPROVEMENT OF FURNACES & BOILERS.

## FEED PREHEAT & RECYCLE HEAT IN EFFLUENTS

| YEAR | CRUDE TO HEATER | PRODUCTS TO COOLERS |
|---|---|---|
| 1960's | 180-200°C | 150-170°C |
| 1970s | 225-250°C | 100-150°C |
| 1980s | 250-275°C | 60-100°C |
| Current | 275-300°C | 50- 90°C |

In a 3MM tonnes per annum refinery

Each 10°C crude preheat:—2.2MM kcal/hr absorbed
—2.5MM kcal/hr fired
—2000 TPA fuel

At US dollars 150/tonne—0.3 million dollars/year

1 OPTIMIZE FLOW CONFIGURATION.

2 MINIMIZE HEAT LOSS TO AIR/WATER INCLUDING HEAT INTEGRATION BETWEEN PROCESS UNITS.

3 OPTIMIZE CLEANING CYCLES.

4 USE OF EXTENDED/POROUS SURFACES.

## SPECIFIC CONSERVATION MEASURES FOR

## AIR COOLERS

1 USE OF AUTOMATIC VARIABLE PITCH FANS.

2 BETTER INLET AIR DISTRIBUTION.

3 USE OF TUBES WHICH MAINTAIN FIN CONTINUITY/ THERMAL CONTACT.

4 MINIMIZE AIR RECIRCULATION.

## REDUCE LOSSES

- THRU CUTTING DOWN AIR LEAKAGES
- BETTER INSULATION (CERAMIC FIBRE FACING)
- BOILER BLOWDOWN CONTROL.
- BY CLEANER SURFACES THRU EFFECTIVE SOOT-BLOWING

## IMPROVE COMBUSTION EFFICIENCY

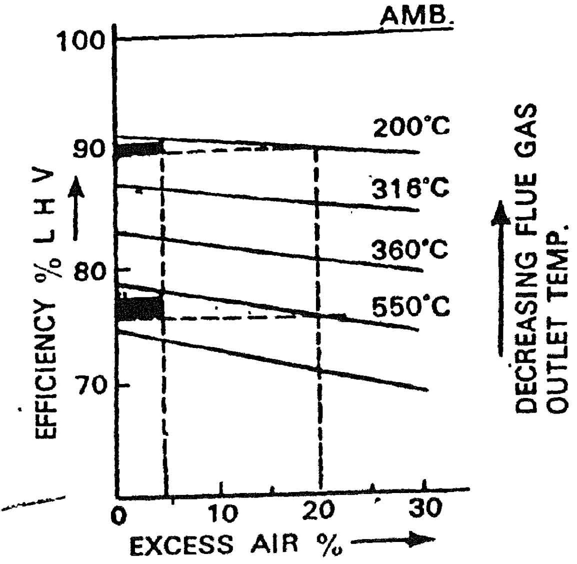
- THRU MORE EFFICIENT LOW EXCESS AIR BURNERS
- COMBUSTION CONTROL INSTRUMENTATION

## RECOVER HEAT IN FLUE GASES

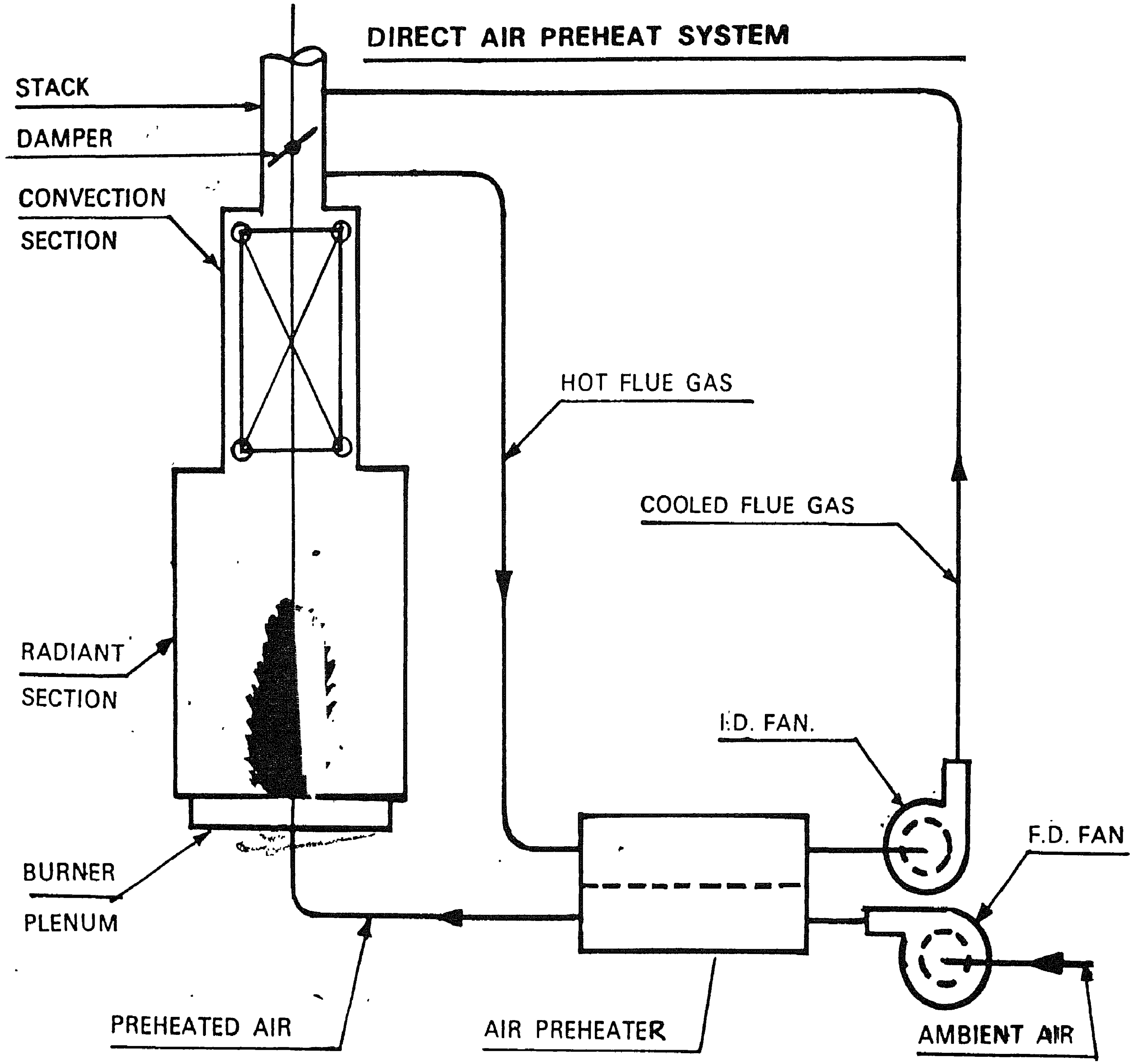
- THRU AIR PREHEATER
- ADDITIONAL CONVECTION AREA
- INSTALL WASTE HEAT BOILER

EIL ENGINEERS INDIA
NEW DELHI

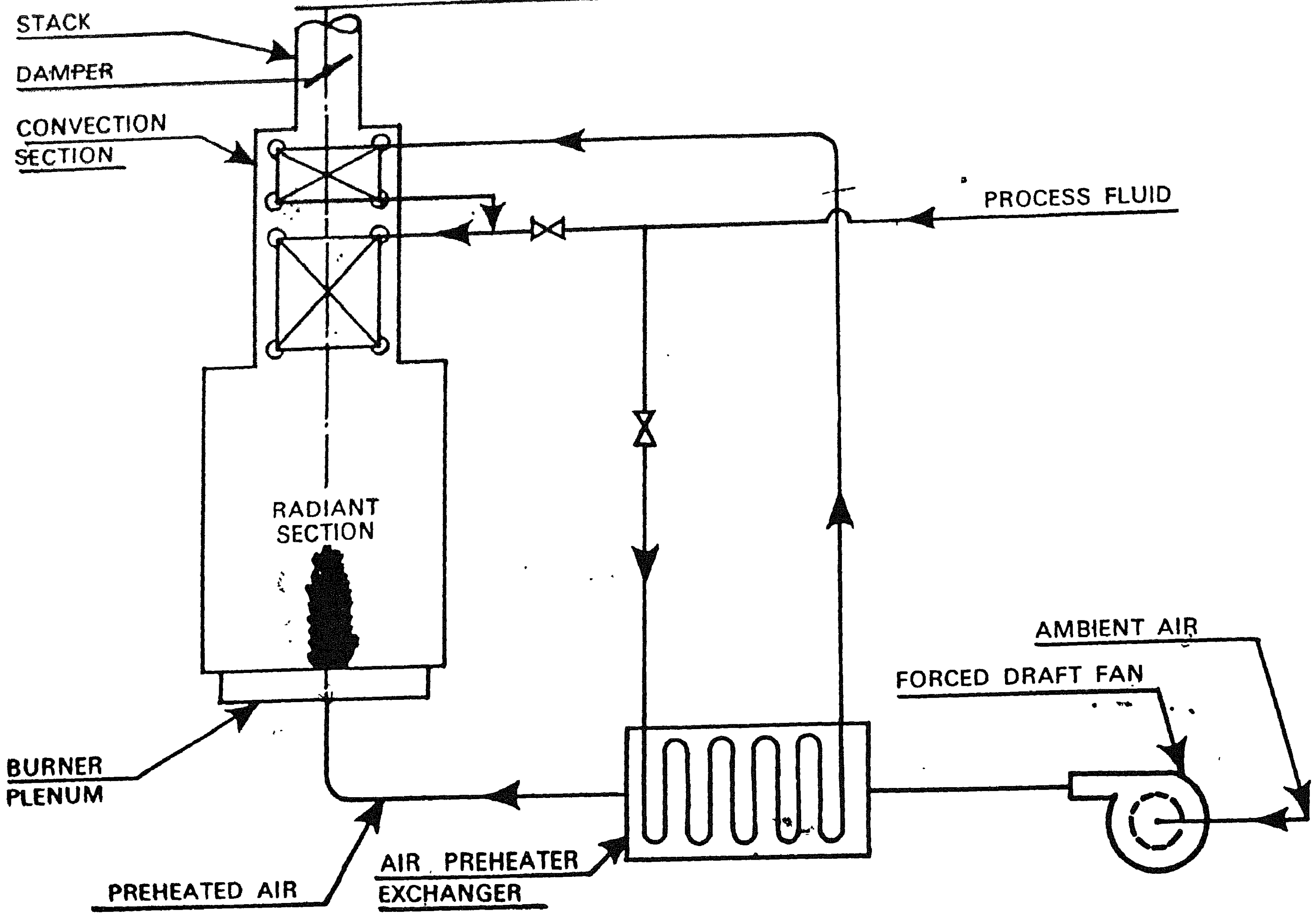
## HEATER EFFICIENCY



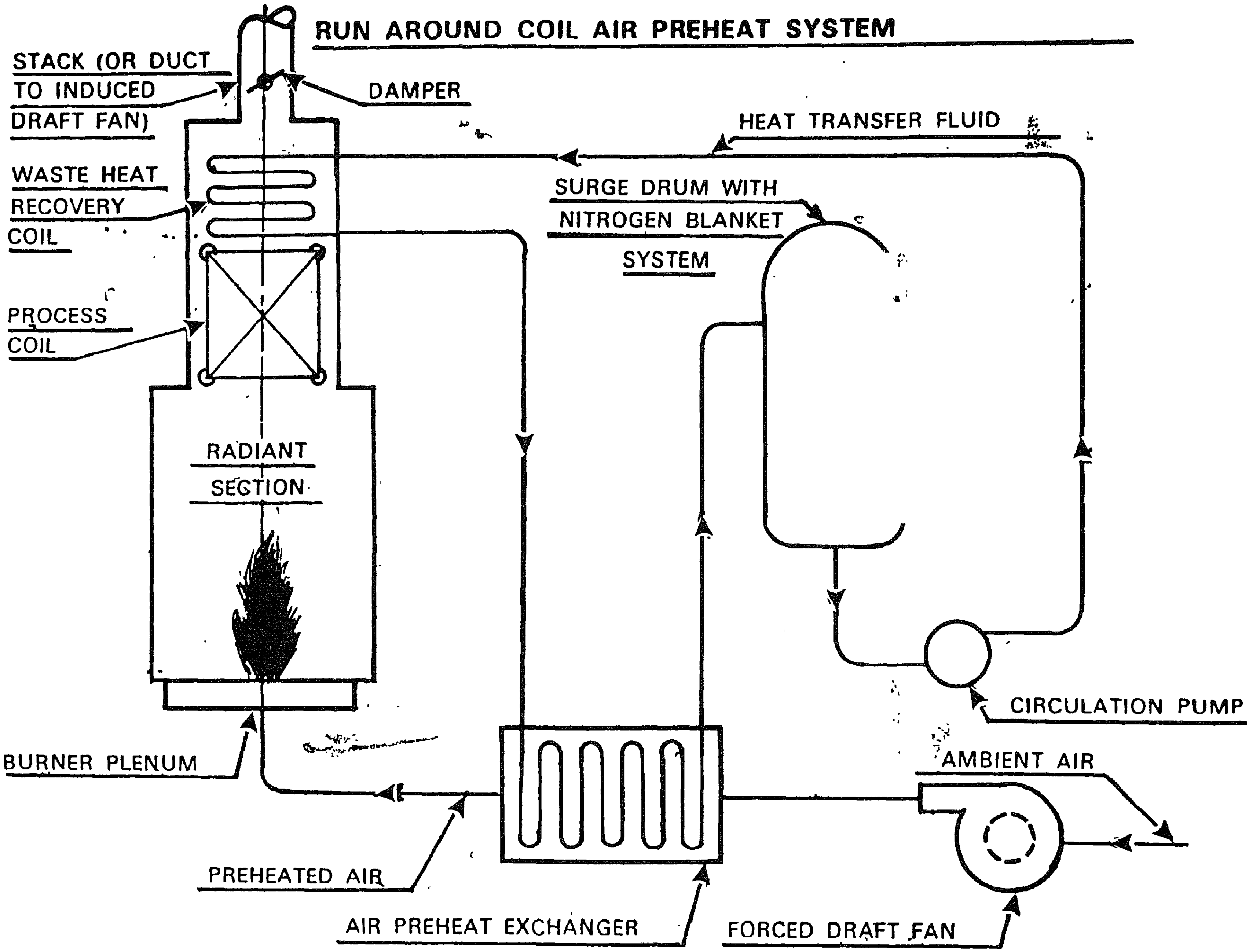
# DIRECT AIR PREHEAT SYSTEM



## SLIP-STREAM AIR PREHEAT SYSTEM



## RUN AROUND COIL AIR PREHEAT SYSTEM



## AIR-PREHEAT EFFECT ON FURNACE OPERATION

- Pressure Profile
  - FD Fan for Air Ducts, APH & Burner
  - ID Fan for Convection Section, Duct, ApH & Stack
- Temperature Profile
  - Increased Flame Temp (Coil Supports)
  - Increased Radiant Flux (Sensitive Stocks)
- Excess Air Reduction
  - Increased Emissivity ($H_2O$, $CO_2$)
  - Decreased Convection Section Duty.

## RETROFIT CONSTRAINTS

1 Process Parameters
  — Superheater Performance
2 Space Restrictions
  — Safety/Maintenance
  — Best Solution Not Possible
3 Use of Recovered Energy
  — Steam User
4 Down Time Allowed

## CASE STUDY

**CLIENT : BHARAT PETROLEUM CORPORATION LIMITED**

**CAPACITY** : 6 MTPA Bombay high crude (1984)

**ENERGY CONSUMPTION :**

Existing Design : 2.64% Wt. of crude
With modifications : 2.21% Wt. of crude
Savings/year : 25,800 tons of crude

| | PROPOSED MODIFICATIONS : | CAPITAL INVESTMENT<br>In million Rupees | Annual Savings |
|---|---|---|---|
| 1. | New heat exchangers | 4.8 | 11.4 |
| 2. | Air pre-heaters for C.D.U. heaters | 21.0 | 41.6 |
| 3. | Air pre-heaters for Boilers | 6.0 | 2.1 |
| 4. | Replacing FPU heater | 30.0 | 21.9 |
| 5. | CO boiler x 1.2 MW turbine | 20.0 | 15.9 |

* Includes basic equipment & components cost only.

# CASE STUDY

## HEAT EXCHANGERS

**CLIENT : BHARAT PETROLEUM CORPORATION LIMITED, BOMBAY**

## ALTERNATIVES

(Present Crude Pre-Heat Temp-188°C)

### 1 IDEAL CASE-REDESIGN TRAIN

Preheat temp. could be increased to 232°C
however not practical due to space constraints

### 2 REPLACING WITH LONG-TUBE EXCHANGERS

Present exchangers have 4.8$^m$ long tubes.
increasing length to 6$^m$ increases area by 25%
and crude terminal temp. can be 204°C. Existing
bundles when requiring replacement could be
replaced with longer tube bundles since space is
available

### 3 OPTIMIZATION WITH ECONOMICAL CHANGES

Relocating some of the existing heat exchangers,
addition of 4 new exchangers with piping
modifications can increase pre-heat to 200°C,
recovering $4.75 \times 10^6$ kcal/hr. Studies also revealed
that pressure drops in some heat exchangers
could be reduced with slight modifications

# CASE STUDY

## C.D.U. HEATERS

**CLIENT** : BHARAT PETROLEUM CORP. LTD.

| | | HEATER-B1 | HEATER-B2 |
|---|---|---|---|
| EXISTING | Type | Box-Type | Forced Draft |
| | Duty-$10^6$ kcal/hr | 39.0 | 41.7 |
| | Fuel | LSHS/S.R./GAS | |
| | Excess Air-% | 45 | 45 |
| | Efficiency- % | 69.7 | 68.0 |
| | Flue exit Temp. °C. | 500 | 545 |
| ADDITIONS | **AIR PREHEATER WITH EXTERNAL CONVECTION SECTION** | | |
| | Duty $10^6$ kcal/hr | 4.83+1.0 | 5.16+2.1 |
| | Flue Temp. in/out°C | 500/204 | 545/204 |
| | Air Temp. in/out°C | 30/325 | 30/325 |
| | F.D. Fan Power kW | 70 | 85 |
| | I.D. Fan Power kW | 120 | 140 |
| NEW | Excess Air % | 10 | 10 |
| | Efficiency % | 89 | 89 |
| **SAVINGS FUEL OIL TPA** | | **9709** | **11574** |

## CASE STUDY

### FPU HEATER B-I

## CLIENT : BHARAT PETROLEUM CORPORATION LIMITED

| | | |
|---|---|---|
| **EXISTING** | Type | Box-type forced Draft |
| | Duty | $19.4 \times 10^6$ kcal/hr. |
| | Fuel | LSHS/S.R./Gas |
| | Excess Air | **150%** |
| | Efficiency | **65.2%** |
| | Flue exit temp. | 450°C |

| | | |
|---|---|---|
| **NEW** | Heater | |
| | Duty | $27.2 \times 10^6$ kcal/hr. |
| | Excess Air | 10% |
| | Efficiency | 90% |
| | Air-Preheater | |
| | Duty | $2.4 \times 10^6$ kcal/hr. |
| | Flue temp. in/out | 450/204°C |
| | Air temp. in/out | 30/325°C |

**SAVINGS FUEL OIL 6559 TPA**

# CASE STUDY

## BOILER

## CLIENT : BHARAT PETROLEUM CORP. LTD.

| | | | | |
|---|---|---|---|---|
| EXISTING | Duty | | $10^6$ kcal/hr. | 16.7 |
| | Fuel | | | L.S.H.S./S.R./Gas |
| | Excess Air | | % | 60 |
| | Efficiency | | % | 80.4 |
| | Flue exit temp. | | C | 310 |
| ADDITIONS | **AIR PRE HEATER** | | | |
| | Duty | | $10^6$ kcal/hr | 1.29 |
| | Flue Temp. in/out | | C | 310/204 |
| | Air Temp. in/out | | C | 30/153 |
| | **F.D. FAN** | Power | kW | 40 |
| | **I.D. FAN** | Power | kW | 70 |
| NEW | Excess air | | % | 60 |
| | Efficiency | | % | 85 |

| | |
|---|---|
| SAVINGS FUEL OIL TPA | 1028 |

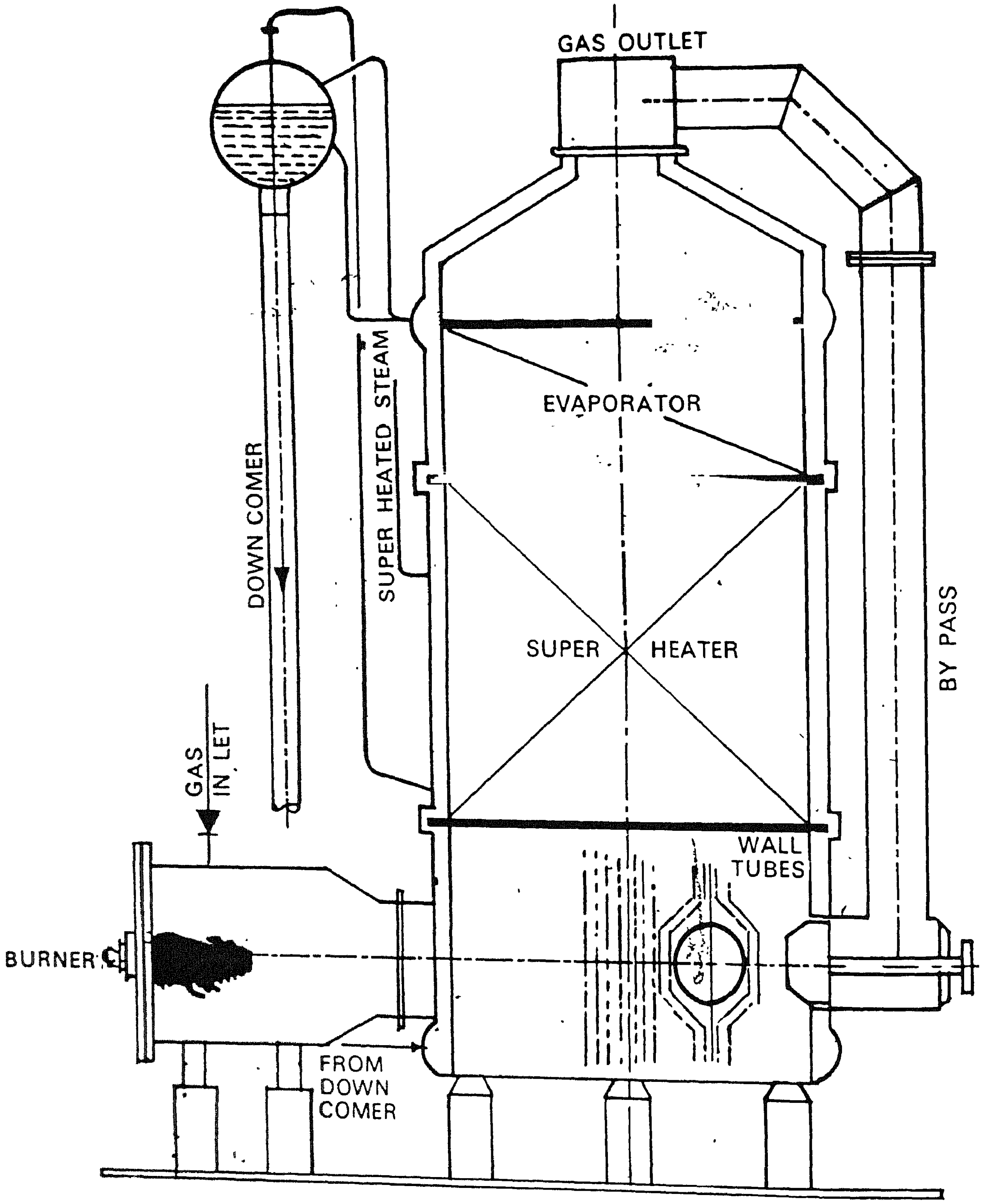
# CASE STUDY

## CO BOILER + TG SET

## CLIENT : BHARAT PETROLEUM CORPORATION LTD.

| | | |
|---|---|---|
| EXISTING BOILER | Steam | 12.5 TPH |
| | Pressure | 21 BAR |
| | Flue inlet temp. | 620°C |
| | **CO BOILER** | |
| NEW SYSTEM | Steam | 24.0 TPH |
| | Pressure/Temp. | 50 BAR/400°C |
| | Flue temp. in/out | 940/250°C |
| | Fuel oil fired | 160 kg/hr |
| | **TURBOGENERATOR** | |
| | Power | 1.2 MW |
| | Back Pressure | 16 BAR |
| SAVINGS | Additional steam | 92000 TPA |
| | Power | 9.5x10$^6$kWh |
| | Fuel oil Fired | (1280 TPA) |

## CO. BOILER


GAS OUTLET
SUPER HEATED STEAM
DOWN COMER
EVAPORATOR
SUPER HEATER
BY PASS
GAS IN LET
WALL TUBES
BURNER
FROM DOWN COMER

P.&D.DIVN.

# ENERGY CONSERVATION
BY M.H. JETHANANDANI

1.0 Energy is basic to production and its efficient use to productivity. Its scarcity limits growth. Economic use of energy is vital for sustaining the very tempo of development.

Slide 1 shows price escalation index from RBI bulletin Jan. 86. This shows that Energy costs are rising much faster than prices of other goods/commodities and this pattern will continue in this country for atleast next twenty years. Power shortages and cuts will also continue. It has been estimated that while it costs Rs.1.25 crores per MW to create additional generation capacity, it costs Rs.30 to 40 lakhs to adopt Energy Conservation measures to save 1 MW power. Economically therefore Energy Conservation measures need more attention.

Slide 2 shows the increase in price index of selected essential commodities. Price index of coal and electricity is higher than other commodities.

2.0 Pulp and Paper Industry is one of the largest consumer of energy. Energy costs constitute nearly 20-24% of production cost in India against 12-14% in advanced countries.

Table 1 shows how energy costs at Ballarpur and Jagadhri have been rising:

TABLE 1 : Energy Costs/Ton of Paper

| | 79-80 | 80-81 | 81-82 | 82-83 | 83-84 | 84-85 | 85-86 |
|---|---|---|---|---|---|---|---|
| Ballarpur | 672 | 837 | 1218 | 1296 | 1623 | 1677 | 1683 |
| Shree Gopal | 1151 | 1272 | 1091 | 1357 | 1764 | 1931 | 2192 |

The increasing cost of energy should therefore become a concern of every body.

Table 2 below shows how the purchased energy at Ballarpur and Jagadhri have been controlled by various energy conservation measures. (These fig. include about 0.15 M K Cal/ton of Energy on effluent treatment).

TABLE 2 : Purchased Energy MKcal/Ton of Paper

| | 81-82 | 82-83 | 83-84 | 84-85 | 85-86 | Jul-Aug 86 |
|---|---|---|---|---|---|---|
| Ballarpur | 13.7 | 12.8 | 13.45 | 12.7 | 10.82 | 10.60 |
| Shree Gopal | - | 12.72 | 13.22 | 12.46 | 12.75 | 12.34 |

3.0 All over the world Paper Industry has made outstanding achievements in Energy Productivity. Published figures of American Pulp & Paper Industry show following achievements.

TABLE 3 : Energy figures of American Industry

| Purchased | 1983 % | 1972 % | Self Generated | 1983 % | 1972 % |
|---|---|---|---|---|---|
| Purchased electricity | 6.4 | 4.4 | Wood residues | 9.8 | 2.0 |
| Coal | 13.9 | 10.6 | Bark | 5.5 | 4.5 |
| Residual fuel oil | 9.4 | 21.2 | Spent pulping liquors | 38.1 | 33.4 |
| Distillate fuel oil | 0.3 | 1.1 | Hydro electricity | 0.5 | 0.4 |
| Gas | 14.6 | 20.9 | | | |
| Other | 1.0 | 1.3 | Other | 0.5 | 0.5 |
| TOTAL | 45.6 | 59.5 | TOTAL | 54.4 | 40.5 |

This shows:

- Increased use of self generated and residue sources of energy from 40.5%, an increase of 34.6%.
- Reduced oil consumption by 55%.
- Reduced total consumption of fossil fuel and purchased energy by 23%.

4.0 We started of with a check list of American Pulp & Paper Institute and Canadian Pulp & Paper Institute. Annexure 'A' lists various energy conservation ideas.

5.0 Some of the case studies of Energy Conservation measures at Ballarpur Industries Limited are given below.

## 5.1 Energy Requirement in Digestor

An energy balance was done on Voith Digestor to check on the actual steam consumption versus theoretical steam consumption. The steam consumption was 2.6 MT/Ton of Pulp when this study had started. Table 5.1 shows that we require 2.40 MT per ton of pulp at a bath ratio of 3.8 and 2.22 MT per ton of pulp at a bath ratio of 3.5. These calculations further led to analysis of other areas where energy was not utilised efficiently.

These areas were:

(a) Proper maintenance of air vent valves.

(b) Avoiding use of superheated steam as it resulted in poor heat transfer coefficient.

(c) Change of chip packing method to increase capacity per batch.

(d) Improved insulation of digestor, pipelines etc.

All these measures particularly increased chip packing reduced steam consumption to 2.0 T/ton of pulp resulting in saving of Rs.32.0 lakhs/annum.

## 5.2 Optimization of blow heat recovery and other operations in Pulp Mill

During the blow of digestor, sudden decrease in the temperature releases steam which could be recovered and used for heating the water for brown stock washing.

Total weight of Black liquor = Black liquor from 1st stage + black liquor in 2nd stage + white liquor + Injected black liquor + chips water + lignin

= 76.10 tonnes

Weight of Pulp = 7.75 tonnes

Heat available from:

(a) Pulp = .15 MK Cal

(b) Black liquor = 4.0 MK Cal

(c) Digestor Shell = .20 MK Cal

Latent heat of vapour at 100°C and 1 atm pressure

= .539 M Cal/tonne

$\therefore$ Steam available per blow = $\frac{4.35}{.539}$

= 8.1 tonne steam

## TABLE 5.1 : VOITH DIGESTER-STEAM/COOK

| | | Heat input/Cook in present operations | Heat input/Cook with reduced bath ratio and increased B/L & W/L Temp. |
|---|---|---|---|
| 1. | Bath Ratio | 3.8 | 3.5 |
| 2. | White liquor temp | 82°C | 85°C |
| 3. | Black liquor | 75°C | 78°C |
| 4. | Steam during blow | 1000 kg | 800 kg |
| | | K.Cal | K.Cal |
| 1. | Chips Heating | 7,36,032 | 7,36,032 |
| 2. | Moisture | 5,30,400 | 5,30,400 |
| 3. | Black Liquor B/L 1st stage | 19,26,925 | 18,21,820 |
| 4. | Remaining B/L 1st Stage | 3,60,360 | 3,60,360 |
| 5. | White liquor 2nd stage | 29,42,940 | 28,41,459 |
| 6. | Black liquor 2nd stage | 7,28,728 | 3,52,352 |
| 7. | Digester shell | 1,22,148 | 1,22,148 |
| 8. | Insulation | 10,000 | 10,000 |
| 9. | Radiation Losses | 1,10,363 | 1,10,363 |
| 10. | Relief | 5,00,000 | 5,00,000 |
| 11. | Unaccounted for | 2,20,750 | 2,20,750 |
| 12. | Total | 81,88,646 | 76,05,664 |
| 13. | Steam/cook | 16,884 kgs | 15,633 |
| 14. | Steam for blowing | 1,000 | 800 |
| 15. | Total steam/Cook | 17,884 kgs | 16,482 |
| 16. | Steam/T Pulp | 2.4 MT | 2.22 MT |

In addition to this 1 tonne of steam is used for blowing the cook.

Steps taken to improve blow heat:

(a) Modification in blow tank to avoid carry over of fibres.

(b) Regular cleaning of trays.

(c) Maintaining circulating condensor water temperature.

(d) Ensuring requisite capacity of circulating water pump.

Heat released during each blow = 5.46 MK Cal/Cook
or 5.00 MK Cal/hr

Heat requirement for heating the water from 30°C to 65°C for brown stock washing plant.

Earlier only 2 MK Cal/hr was recovered. With the above stated steps we have been able to avoid the steam usage for brown stock washer.

This means a saving of Rs.320/- per hour, or a saving of Rs.25 lakh per annum.

### 5.3 Steam requirement on PM 6

The average production is based on 1.8 tonnes per hour.

% Moisture input to dryer = 62%
% Moisture at Pope reel = 3%
B.D. paper = 1.746 tonnes/hr.

Total quantity of water + fibre entering = 4.595 tonnes/hr.

Quantity of water entering = 2.849 tonnes/hr.

Quantity of water evaporated = 2.795 tonnes/hr.

(1) Heat with incoming paper

= 1746 x .33 x 35 + 2,849 x 1 x 35

= 133893 KCal/hr.

(2) Heat with outgoing paper

= 1746 x .33 x 65 + 54 x 1 x 65

= 40962 K Cal/hr.

(3) Heat required for evaporation

= 2795 kg/hr x 550

= 1537250 K Cal.

(4) **Heat with incoming air**

= 3 x 4200 x 1.293 x .242 x 35

= 137992 K Cal/hr.

(5) **Heat with outgoing air**

= 3 x 4200 x 1.293 x .242 x70

= 275984 K Cal/hr.

**Heat Loss due to radiation and convection**

There are 17 paper driers and 4 felt dryers on machine No.6. For a surface temperature of 100°C, it is estimated that:

Radiation losses = 505 KCal/$M^2$/hr

Convection losses = 320 KCal/$M^2$/hr

∴ Total losses = 1,65,000 KCal/hr

Total heat required = 1747 311 KCal/hr

Steam required = $\frac{1747311}{521}$ = 3354 ton of steam

If size press is working then approximately 0.30 ton of water is added per ton of paper which has to be evaporated.

∴ Total steam required = 3894 ton of steam per hour.

Steam consumption per ton of paper = 2.16 ton/ton of paper.

In dandy we require approximately 0.5 ton/ton of paper on Machine No.6.

∴ Total theoretica l steam consumption = 2.66 ton/ton of paper.

The moving average of steam consumption of Machine No.6 was 4.21 ton/ton of paper in the month of May 1985, which was reduced to a moving average of 3.15 ton of steam/ton of paper by taking various measures.

On Paper Machine No.6 there was a provision of using flash steam only in first 3 dryers. After closing the condensate vent valve the pressure in the tank was rising as high as 0.6 kg/$cm^2$ gauge. There was a tendency of opening live and flash steam simultaneously in the same dryer as a result live steam was rushing into condensate tank. This resulted in flash and some live steam to get vented. Even after shutting live steam valve there was a residual pressure in condensate tank in the range of 0.2 to 0.4 kg/$cm^2$. Subsequently a flash steam connection was provided to additional dryer No.4. This gave full utilization of flash steam in the range of 280 to 300 kg/hr.

## 5.4 Boiler Efficiency

Most of coal fired boilers in India are operating at low efficiencies and quite often no attempt is made by operating depth to determine as to where the losses are occuring. Provision of additional facilities like ultimate analysis of coal, Orsat apparatus, use of portable flue gas analyser, Bomb Calorimeter are absolutely essential. Insistence on periodic efficiency monitoring can bring about significant improvement.

Provision of $O_2$/CO Online analysers can help efficiency improvement of 1-3%. Use of microprocessor combustion controls can further reduce losses by 1-1½%.

By scrapping old chain grate stoker/stationary grate boilers with spreader stoker boilers, we have improved coal to steam ratio considerably and achieved saving of Rs.42 lakhs annually but our boiler efficiency continues to be still low i.e. 66-70% as against our target of 72%.

An improvement of efficiency by 4% would give us saving of Rs.30 lakhs/yr at Ballarpur Unit. The measures in hand are:

1. Periodic efficiency testing.
2. Microprocessor controls on boilers.
3. Installation of oxygen analyser and use of portable flue gas analyser to determine air leakages.
4. Controlling air distribution to grate particularly at low loads.
5. Use of hydraulic cleaning of boiler tubes to improve heat transfer.
6. Reduce losses due to blow down etc.

## 5.5 Pumps

The pumps alone consume about 40 to 50% of the total energy consumed per tonne of paper. In most cases it has been found that pumps are oversized and design characteristics do not match system characteristics. A review of pump sizing can lead to significant savings. As a first step one can instal pressure gauges and determine pump differential head (actual) v/s design. This can itself give lot of clues.

## Case Study:

### (1) Mill water pumping from pump house

In Pump House the main distribution header pressure was maintained at 3.2 kg/cm$^2$ so that sufficient water is available to all section of mills including pulp mill having highest operating floor connected to this header. This was as per recommendation of M/s. Voith and accordingly pumps were selected to operate at duty point 'A' as shown in the curve.

Later on after some years a separate pump was installed having a total head of 40 M to cater to only Pulp Mill requirement and the header pressure was brought down from 3.2 kg/cm$^2$ to 1.8 to 2.0 kg/cm$^2$ so that sufficient water is available for all the balance sections.

A detailed study was conducted by Unit Technocrates and Energy Conservation Cell on Mill Pump House which revealed that the pumps were working a total head of 25 M only as shown in the curve "Point B" and in this region the pump efficiency and power consumption cannot be predicted.

The total water consumption at this pressure were calculated and accordingly a pump was installed in the Pump House having an efficiency of 84 to 86%. The results are as follows:

| No. of pumps running earlier | Running load | No. of pumps running now | Running load |
|---|---|---|---|
| 2 Nos. big pumps (10 UP 3) | 210 Amp. each | 1 No. Big Pump (16 UPHI) | 270 Amp. |
| 1 No. small pump (6/8" medivane) | 60 Amp. | | |
| | 480 Amp. | | 270 Amp. |

Saving in power = $\frac{1.73 \times 210 \times 420 \times 0.85}{1000}$

= 129.7 KWH

Or Saving in Rs. per annum = $\underline{129.7 \times 24 \times 330 \times 0.72}$

= 7,39,600

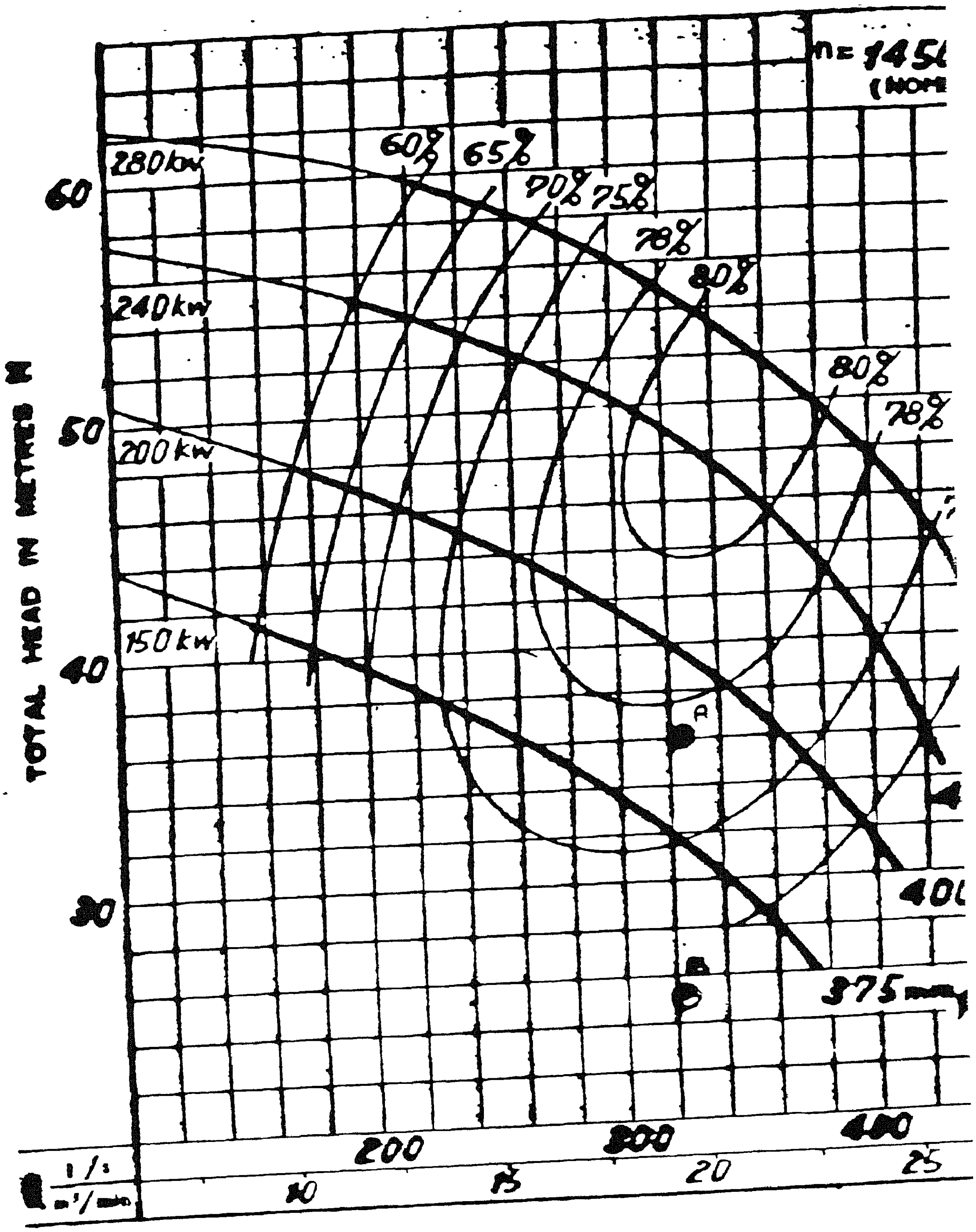
Say Rs.7.4 lakhs

P.&D.DIVN

**Case**

(1

# PERFORMANCE CURVES OF PUMP TYP



A - DESIGN OPERATING POINT

B - ACTUAL OPERATING POINT

## (ii) Pulp Mill and Machine House Pumps

A survey was carried out to locate inefficient pump in the above plants. The capacity of the pumps were established after doing the mass balance of these specification and pressure were noted down. It was observed that there would be a saving of around 40 Unit/Ton of paper by replacing around 32 nos. pumps and motors in these sections i.e. against an investment of around Rs.20.0 lakhs. The saving will be around Rs.25 lakhs. Has a pay back period of less than a year.

## 6.0 Constraints in Energy Conservation Efforts

### 6.1 Technological Developments:

There are a number of untried but very promising technologies available for reducing energy consumption. Among the barriers to innovation in Energy Technology are:

- the risks associated with adoption of new techniques and new applications of existing technologies, particularly when they are not central to the production process.
- Lack of authentic information, reliability and economics of new equipment and processes.
- Weakness of Industry which manufactures and supplies conservation equipment and systems.

Aim of Energy Conservation Demonstration Scheme as operated in U.K. is to accelerate adoption of new or improved energy use technology by overcoming these barriers. The Scheme

- provides grants to offset risks associated with novel projects. In return, companies must allow their projects to be monitored or reported on by independent consultants.
- Disseminates independent technical and economical information about projects to other potential users.
- Provides marketing and technical back up to energy conservation equipment supply industry.

### 6.2 Modernization of plants

There are lot of equipments which have been used world over but are not yet available in India and also testing equipments which can lead to significant energy savings. Imposition of 30% import duties cannot but discourage use of such equipments. A typical list (but not exhaustive) is given below:

- Ultrasonic flow meters
- Portable flue gas analysers
- Oxygen/CO analyser
- Online drainage tester
- Moisture measurement
- Digestor weighing systems
- Online analysers
- Reliable steam flow meters, annubars etc.
- Pressure gauges for slurry, pulp etc.
- Conductivity analysers
- Ultrasonic trap survey instruments
- Smelt bed temp. measurement
- Instruments for paper formation studies
- High consistency pulp pumps
- Low pressure drop centricleaners
- Oscillating showers and shower nozzles
- Ceramic foils and covers
- Efficient vacuum pumps
- Falling film evaporators
- Felts and wires

### 6.3 Proper Energy Management Approach

Another barrier in Energy Conservation efforts is lack of proper energy management approach. Following characteristics are required for effective energy managements approach:

- An awareness throughout all the ranks that Mill Manager cares about energy.
- Develop aggressive policies and programmes.
- Formation of an energy committee composed of right people.

- Conduct meetings regularly.
- Have a proper energy reporting system.
- Accountability at the lowest possible level with available measurement.

It is essential that each Unit has an Energy Manager (not connected with day to day operations) to co-ordinate all activities related to Energy.

## 6.4 Government Incentives

At present Government does not have many incentives for energy conservation projects. The following forms of Govt. support are required at national level:

- Provision of taxes and other incentives as well as soft financing for energy efficient equipments.
- Reduction/exemption of import duties.
- Discourage energywise inefficient units.
- Advisory bodies to assist and guide the industry to adopt energy saving technologies.
- Ensure sustained and reliable power supply.
- Second-hand equipment imports to be encouraged only if they are energy efficient.
- Proper training in the field of energy conservation.

## 6.5 Management Support

Management support is an essential requirements for energy conservation programme. The management must provide following for energy conservation:

- Enough funds for energy conservation projects.
- Manpower for Energy Conservation.
- Acceptance of new technologies.
- Develop Research and Development Department.

# CHECK LIST OF ENERGY SAVING IDEAS

**Woodroom, Woodyard, Hog Fuel Preparation**

- -Use waste process hot water in woodrooms to reduce steam requirements.
- -Improve bark burning efficiency by improving pressing of wet bark prior to firing.
- -Use chipped forest refuse (birch, aspen, etc.) and peat as fuel, reducing oil use.
- -Maximise bark burning by changing operational routine of wood room.
- -Recover wood and bark fines for fuel.
- -Install bark dryer.
- -Improve hog fuel handling to improve boiler efficiency and eliminate frequent downtime which requires fossil fuel make-up (ECO WHP 1).
- -Replace pneumatic conveyors with belts.

**Mechanical Pulping and Bleaching**

- ✓ -Reduce fresh water consumption on showers in pulping and bleaching areas.
- -Recover waste heat from grinders and refiner exhausts.
- ✓ -Replace fresh water showers or dilution with white ✓ water.
- -Automatic freeness control (ECO GW 2).

**Chemical Pulping, Washing and Screening**

Digesters

- ✓ -Optimize target KAPPA number.
- ✓ -Raise sulphidity to reduce lime demand and hence kiln fuel (ECO KP 23).
- -Insulation on Kamyr digester (ECO KP 27).
- ✓ -Install chip packers in batch digester.
- ✓ -Use two level steaming in batch digester.
- ✓ -Computer control to level steam loads and increase boiler efficiency (ECO KP12 & KP17 & KP25).

Brownstock Washing

- ✓ -Improve recovery of waste liquor for firing in chemical recovery units.
- ✓ -Reduce fresh water consumption on showers in bleaching, pulping, and paper making areas.
- ✓ -Control wash water flow in accordance with production rate and evaporater load.
- ✓ -Improve brown stock washing to reduce evaporation load.
- ✓ -Replace steam doctors on washers with air doctors.
- ✓ -Replace fresh water showers on knotters with liquor to reduce evaporater load (ECO Pulp 1).
- -Select hottest feasible evaporater condensate for brownstock washing (ECO KP 1).
- -Heat washer shower water by heat exchange with bleach caustic extract.
- ✓ -Use waste warm water for unbleached decker seal tank make-up (ECO KP 8).

Screening

- ✓ -Heat Brownstock decker water with waste heat to warm bleach plant input stock.
- ✓ -Eliminate unnecessary screens (ECO KP 9).
- ✓ -Shut down some screens when production is low.

**Chemical Pulp Bleaching**

- ✓ -Recycle warm filtrates in bleach plant.
- ✓ -Reduce fresh water consumption on showers in bleaching, pulping and paper making areas.
- ✓ -Eliminate fresh water use in washer ring brackets (ECO KP 4).
- ✓ -Replace fresh water with white water in bleach decker hydraulic doctor (ECO KP 5).
- ✓ -Replace fresh water with waste warm water for caustic dilution (ECO KP 15).
- ✓ -Replace trash removal screens with large diameter cleaner (ECO KP 16).
- ✓ -Heat shower water by exchange with contaminated condensate (ECO CON 5).

**Chemical Recovery and Evaporators**

Evaporators

- ✓ -Recover evaporator flash steam.
- ✓ -Modify evaporator for better economy.
- ✓ -Improve brown stock washing to reduce evaporation load.
- -Install pre-evaporation unit on liquor evaporator system using waste heat.
- -Use automatic density control to optimize evaporator operation.
- -Install new ejectors or replace them with vacuum pump.
- -Install stand-by liquor storage in earthen basin to retain temporary overloads of weak liquor (ECO Sulp 2)
- -Transfer as much as possible of the evaporation load from concentrator to more efficient multiple effect evaporators by acid cleaning latter (ECO KP 22).

Recovery Boiler

- -Improve soot blowing system on recovery boilers to minimise steam usage.
- -Improve smelt tank heat recovery system.
- -Use compressed air instead of steam for smelt shatter jet.
- -Heat feed water make-up with recovery boiler scrubber effluent (ECO SP 19).
- -Use speed control rather than damper control for fans.
- -Improve recovery boiler operation to eliminate oil firing (ECO SP 1).

CHECK LIST OF ENERGY SAVING IDEAS (con't)

## LIME KILN

- **Improve efficiency of lime kiln**
- **Insulation to be checked to minimise losses**
- **Possibility of recycling flue gases to utilise volatile from coal**

### Paper Machine and Pulp Drying

Wet End

-Replace suction presses with grooved presses and reduce vacuum requirements (ECO PM 8 & 20).

-Increase press loading on paper machines to reduce drying requirements (ECO PM 11).

-Lower felt moisture by additional vacuum (ECO PM 19).

-Reduce fresh water consumption on showers (ECO GEN 3).

-Close up paper machine white water systems with objective of eliminating wire pit steam (ECO PM 3, PM 5 & KP 14).

-Improve vacuum systems on paper machine couch rolls to reduce dryer loadings.

-Replace steam ejector by vacuum pump on deculator.

-Upgrade felt conditioning on paper machine.

-Eliminate felt conditioning (ECO PM 22).

-Eliminate felt dryers (ECO PM 4).

-Replace ventanip roll with stainless "C" roll (ECO PM 1).

-Replace heated fresh water with white water for cleaner reject sluicing (ECO KP 13).

-Install steam shower to improve pressing (ECO PM 23).

Dryer

-Reduce pocket ventilation temperature (ECO PM 21).

-Reduce pressure in paper dryers to increase steam flow through turbogenerator (ECO SP 17).

-Recover and reuse paper machine press water.

-Reduce paper machine dryer drive loads by improving condensate removal.

-Install thermocompressors on dryer steam systems (ECO PM 7 & CON 4).

✓ -Improve capability of paper machine moisture control systems.

-Replace condensers with direct cooling by treated boiler feed water make-up (ECO PM 15).

✓ -Install dual syphons in dryer cans to improve condensate removal (ECO PM 12).

-Employ computer controls on paper machines for basis weight and dryer controls to minimise over-drying.

Air System

✓ -Upgrade paper machine enclosed hoods.

-Upgrade heat recovery capability of waste heat economisers on paper machine and pulp machine dryers.

-Reduce pressure differential across FLAKT dryer (ECO KP 19).

✓ -Limit air exhaust on open dryer hood in winter (ECO PM 9).

Miscellaneous

✓ -Replace cold water intakes to warm water systems with used cooling water (ECO PM 16).

✓ -Seal hotwell overflow to reduce loss of flash steam (ECO SP 22).

### Steam Plant and Turbines (except recovery boiler)

Boiler

-Install new bark fired boilers.

✓ -Install new boiler controls, gas analyzers, and other devices to improve boiler efficiency.

✓ -Install boiler blowdown heat recovery units.

-Convert oil fired power boilers to allow partial or full hog fuel firing.

-Burn waste oil as fuel.

-Improve oil burner operation and maintenance and design to increase efficiency.

-Upgrade atomizing steam on oil fired boiler.

-Reduce burner atomising steam pressure (ECO SP 9).

-Replace defective tubes in combustion air heater (ECO SP 5 & 30).

-Improve gas/oil burners (ECO SP 6 & SP 24).

-Improve undergrate air distribution in hog fuel boiler (ECO SP 10).

✓ -Use warm air from top floor of building as supply for FD fan (ECO SP 11 & SP 20).

-Improve reliability of auxilliary fuel ignitors in hog fuel boiler to avoid the need to maintain one gun in operation to protect against loss of fire (ECO SP 14).

-Replace steam spreaders with mechanical spreaders in hog fuel boiler (ECO SP 15).

Turbine

✓ -Install back pressure turbines for either electric generation or direct mechanical drives.

✓ -Transfer steam from low efficiency local turbine to central turbo-generator by replacing local turbine with electric motor (ECO SP 27 & 32).

✓ -Convert medium pressure steam consumers to lower pressure for increased electrical generation.

## CHECK LIST OF ENERGY SAVING IDEAS (con't)

### Feedwater

-Upgrade and rehabilitate boiler feed water heating systems.
-Install water softeners for boiler feed water to reduce blowdown.
-Preheat boiler feedwater with mill effluents.
-Heat boiler feedwater by using it as compressor cooling (ECO SP 31).
-Preheat boiler feedwater with flash steam from condensate collecting tank (ECO SP 23).
-Heat boiler feed water with flue gas and paper machine hood vent.
✓ -Use warm water from the evaporater surface condenser to supply the boiler feedwater treatment system (ECO SP 3).
✓ -Recover hot water from seal gland exhausters in turbines (ECO SP 6).
✓ -Divert deaerator vent from atmosphere to feedwater heater (ECO SP 7).
✓ -Install economisers to heat feedwater in a high temperature stack (ECO SP 13).
✓ -Minimise recirculation at feedwater pumps (ECO SP 29).

### Miscellaneous

✓ -Reduce service water pressure (ECO SP 2).
✓ -Eliminate leakage from HP steam header to LP header (ECO SP 4).
-Insulate bunker C storage tank (ECO SP 21).
✓ -Monitor and check condensate return rates to detect losses (ECO CON 1).

### Mill-Wide Process Heat

✓ -Pressurise condensate recovery systems to avoid unnecessary cooling for pumping purposes (ECO CON 8).
✓ -Scheduled maintenance of steam traps (ECO CON 3 & 6).
✓ -Upgrade steam line and process equipment insulation systems (ECO GEN 1).
-Upgrade steam condensate recovery systems.
-Reclaim transformer cooling water.
-Reclaim compressor cooling water (ECO SP 25).
✓ -Increase use of warm surplus white water for stock dilution system.
-Replace, upgrade or improve maintenance of heat exchanger units.
-Increase heat recovery from exhaust gaseous streams.
-Use waste process hot water in woodrooms to reduce steam requirements.
-Recover waste heat from grinder and refiner exhausts
-Replace or repair leaking fresh water valves.
✓ -Reduce direct steam heating.
✓ -Install steam meters.
-Install water meters.
-Install mechanical seals on liquor pumps.
✓ -Heat all stock and white water pump seal water with waste heat (some of it cools the process).

### Mill-Wide Heating and Ventilating

-Heat building make-up air with exhaust heat using glycol intermediary to avoid freezing in very cold weather (ECO PM 10).
-Reduce paper mill building ventilation exhaust heat losses, commensurate with humidity limitations, during colder weather.
✓ -Use paper mill exhaust air to heat boiler room supply air.
-Reduce heating in storage areas not normally staffed.
-Change sheave sizes on exhaust fans, winter vs. summer conditions.
-Insulate buildings. This is almost always economically attractive unless building is heated by unrecoverable waste process heat. An example is described in ECO PM 14. Most mill buildings are inadequately insulated relative to to-day's energy costs.
✓ -Use infra red viewer to locate heat losses (ECO GEN 1).
-Minimise make-up air (ECO PM 18).
✓ -Energy audit of steam and condensate losses (ECO GEN 5).
-Minimize heat losses through building openings such as windows and doors.

### Mill-Wide Electrical

#### Lighting

✓ -Replace incandescent lighting fixtures with more efficient fluorescent sodium or mercury vapour units and use skylights and windows when possible, especially in storage areas (ECO ELEC 5 & 7).
✓ -Automate outside area lighting (ECO ELEC 1).

#### Power

✓ -Shut down unnecessary agitators (ECO ELEC 3 & 4 and PM 17).
✓ -Modify utilisation and selection practices of process equipment such as pumps, fans etc. to ensure optimum operating efficiency.
✓ -Reduce compressed air use.
✓ -Use variable speed drives to control pump discharge flow or pressure.
-Upgrade hydraulic turbines.
-Install automatic peak demand control on grinders.
-Review electric and gas contracts to optimize energy use.
-Study inter-relationship of cogeneration, steam and fuel to optimize energy consumption.
-Install peak load controllers (see ECO ELEC 6) for one application).
✓ -Install capacitors for power factor correction.
✓ -Modify electric motor selection standards to ensure operation at optimal efficiency.
✓ -Convert continuously running pumps to automatically controlled intermittent operation where feasible (This is most commonly useful on cooling water pumps, examples are described in ECO PM 13 & GEN 4).

# INTRODUCTION

STEEL INDUSTRY HIGHLY ENERGY INTENSIVE

- HIGH TEMPERATURE PROCESSES
- BATCH TYPE RATHER THAN CONTINUOUS

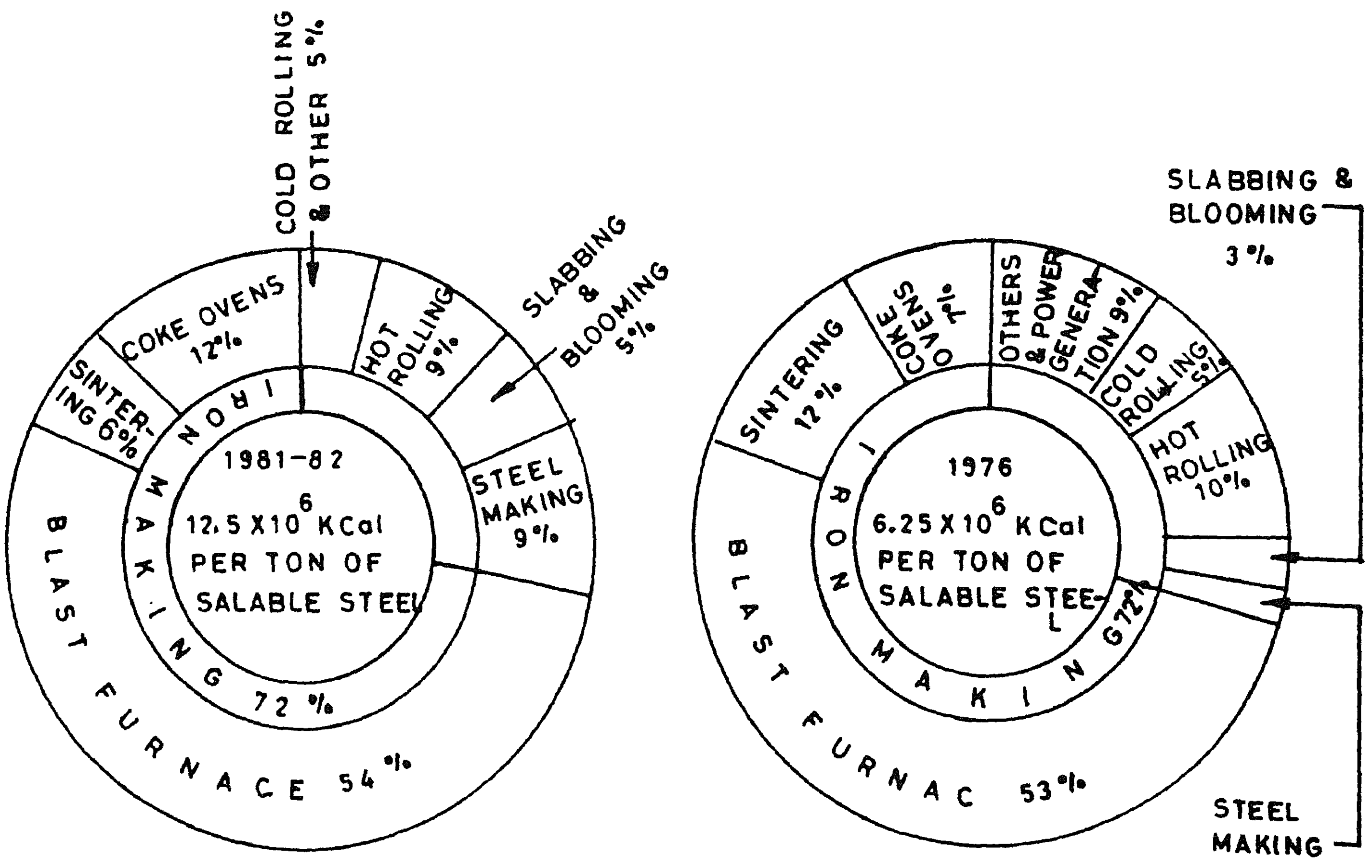
## SPECIFIC ENERGY CONSUMPTION

| | |
|---|---|
| – INDIAN STEEL WORKS | 9-16 G. cal/t steel |
| – ADVANCED COUNTRIES LIKE JAPAN | 4-7 G. cal/t steel |

# ENERGY INPUTS TO STEEL PLANTS

- COKING COALS
- STEAM COALS
- PETROLEUM FUELS
- PURCHASED ELECTRICITY

ABOUT 80-90% OF ENERGY INPUT IS THROUGH COKING COALS



ROURKELA STEEL PLANT

NIPPON STEEL

FIG. 5

COMPARISON OF ENERGY DATA

RDCIS

# CONCLUSIONS FROM ENERGY DATA

- SPECIFIC LEVEL OF ENERGY CONSUMPTION IN INDIAN STEEL PLANTS HIGH ( NEARLY DOUBLE )
- CONSUMPTION OF ENERGY IN IRON ZONE NEARLY 70% FOR INDIAN AND FOREIGN PLANTS
- FUEL UTILISATION EFFICIENCY IN FURNACES POOR

# PRIORITY AREAS FOR ENERGY CONSERVATION

- REDUCTION OF COKE RATE
- EFFICIENT FUEL UTILISATION
- INTRODUCTION OF WASTE HEAT RECOVERY SYSTEMS

# IRON MAKING

| PARAMETER | UNIT | INDIA | ABROAD |
|---|---|---|---|
| COKE RATE | kg/thm | 750 – 1150 | 450 – 500 |
| COKE ASH | % | 25–29 | 8–10 |
| $M_{10}$ |  | 11–18 |  |
| % SINTER |  | 0–65 | 80–95 |
| RAW STONE | kg/thm | 350–550 | 5–10 |
| BLAST TEMPERATURE | °C | 600–1000 | 1100–1350 |
| TOP PRESSURE | Atmg | 1.4–1.5<br>(ONLY BSL) | 2.5–3.5 |
| STABILITY OF OPERATION |  | UNSTABLE | STABLE |

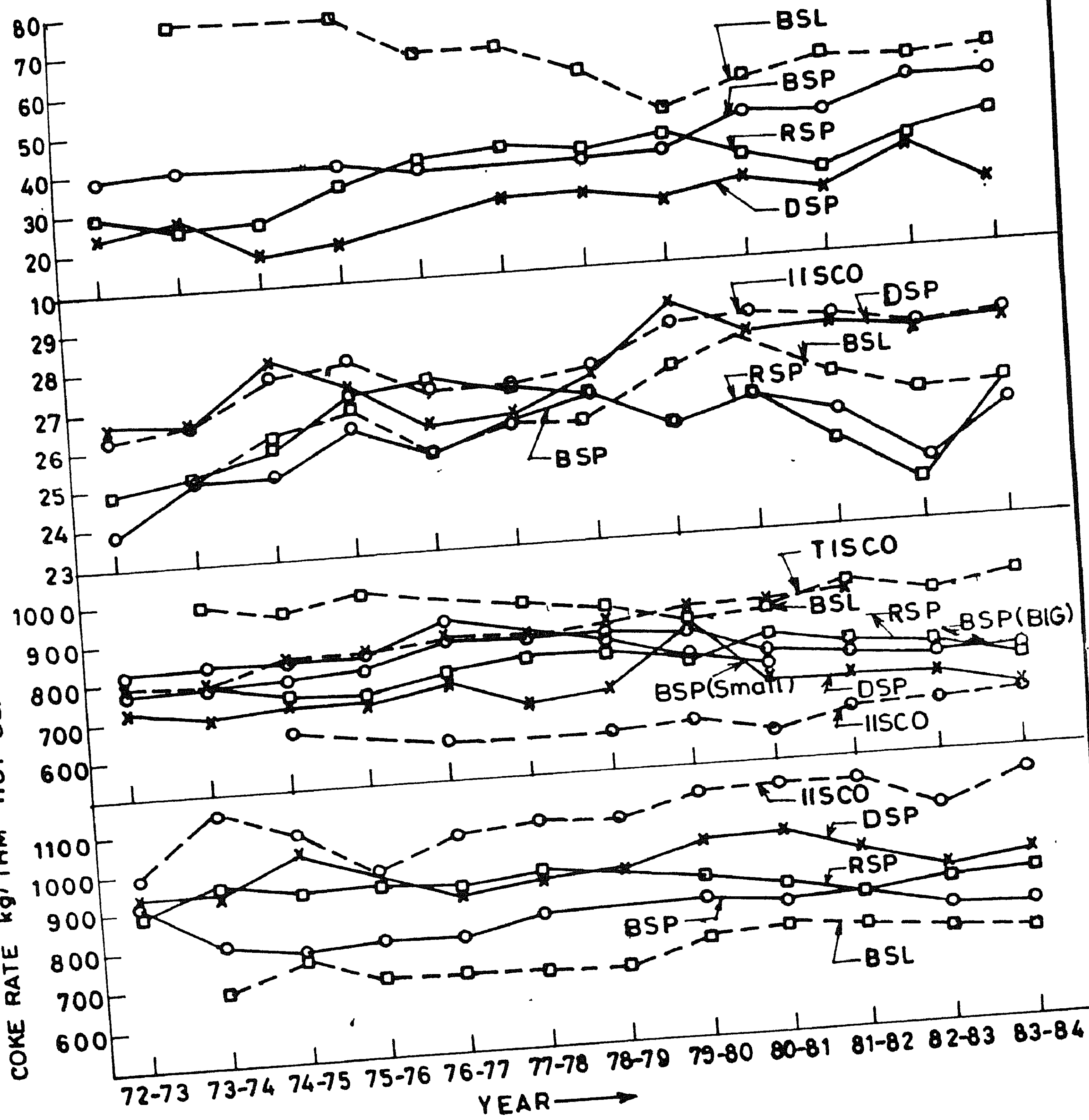


FIG 7

IMPORTANT PARAMETERS IN BLAST FURNACES

RDCIS

# STEEL MAKING

- HIGH RATIO OF O.H. OXYGEN STEELMAKING — 55 %
- HIGH SPECIFIC FUEL CONSUMPTIO
- CONVENTIONAL INGOT CASTING ROUTE

# ROLLING MILLS

- OBSOLETE COMBUSTION SYSTEMS IN FURNACES
- HIGH HEAT LOSSES THROUGH COOLING WATER ( SKID )
- HIGH HEAT LOSSES THROUGH REFRACTORIES
- UNSTABLE MILL OPERATION
- HIGH TRACK TIME

# ENERGY CONSERVATION MEASURES

- OPERATIONAL IMPROVEMENTS
- EQUIPMENT IMPROVEMENT
- MODERNISATION MEASURES

# OPERATIONAL IMPROVEMENT

- GOOD HOUSEKEEPING
- OPTIMUM NUMBER OF FURNACES
- HARDLY ANY CAPITAL INVESTMENT
- CONTINUOUS FOLLOW UP

# EQUIPMENT IMPROVEMENT

MARGINAL INVESTMENT GOOD RETURN

- INSULATION OF COLD BLAST MAIN
- MINIMISING LEAKAGE OF HOT BLAST
- IMPROVED COMBUSTION SYSTEMS
- CERAMIC FIBRE INSULATION
- SKID MODIFICATION IN REHEATING FURNACES

# MODERNISATION MEASURES

CAPITAL INTENSIVE

- STAMP CHARGING
- SINTER PLANT MODERNISATION
- INTENSIFICATION OF BLAST FURNACES
- REPLACEMENT OF O.H.
- ADOPTION OF CONTINUOUS CASTING
- MODERNISATION OF MILLS
- WASTE HEAT RECOVERY SYSTEMS

# ENERGY CONSERVATION EFFORTS OF SAIL

- LIME DUST INJECTION
- HIGH BASICITY SINTERING
- EXTENDED HOOD IN SINTERING
- COLD BONDED PELLETS
- EXTERNAL DESILICONISATION AND DESULPHURISATION
- OPTIMUM THERMAL AND OXYGEN LANCING REGIME IN O.H.
- OXYGEN ENRICHMENT OF COMBUSTION AIR
- CERAMIC FIBRE IN SOAKING PITS
- MODIFIED COMBUSTION SYSTEM IN REHEATING FURNACES AT IISCO

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# Energy Scene—Constraints, Concept and Conservation

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## 1. Introduction

Steel industry being highly energy intensive is and will continue to be one of the major consumers of energy. This is mainly due to the fact that the various steelmaking processes are performed at high temperatures. Further, the steelmaking processes are of batch type rather than continuous type. This results in high level of wastage of input energy.

The specific energy consumption of Indian steel plants ranges between 9-16 Gcal/t of saleable steel, (average being 12 Gcal/t). In the advanced countries like Japan, it is of the order of 4-7 Gcal/t. the objective is to bring down the specific energy consumption in the Indian steel plants to a level of about 7-8 Gcal/t of saleable steel within the next 10 years.

## 2. Energy Inputs to Steel Plants

The major energy inputs to the steel plants are:

i) Coking coals for production of coke used in hot metal production;
ii) Non-coking coals used for the generation of steam and power in the captive power plants;
iii) Purchased electricity to supplement in-plant generated power for running of electrical equipment;
iv) Purchased petroleum fuels like fuel oil, naphtha, LSHS etc. to meet any shortfall in the availability of by-product fuels like coke oven gas, tar, B.F. gas,

About 80-90% of the energy input to the steel plants comes through coking coals. Purchased electricity accounts for only 2-3% of the total energy input to the steel plants.

## 3. Energy Input Data

Table-1 shows the energy input to the SAIL steel plants during the year 1983-84. It may be seen that for production of 4.74 million tonnes of saleable steel, the SAIL steel plants consumed about 11.24 million tonnes of coking coals, 2.26 million tonnes of steam coals, 0.23 million tonnes of petroleum fuels and 2.38 $\times 10^6$ MWH of purchased electricity. The trend in the energy consumption pattern during the last few years is shown in Figure 1. It may be seen that for a 60% of increase in the saleable steel production during the last 10 years, the increase in the energy consumption is about 90%. Further, the consumption of petroleum fuels during the same period has increased roughly by about 80%. During the period 1976-77 to 1983-84, the fuel bill has increased from a level of Rs. 240 crore to Rs. 860 crore even though the level of saleable steel production has somewhat decreased (see Figure 2). It may be mentioned here that in the developed countries there is a definite downward trend in the specific energy consumption levels whereas in the Indian steel plants there is hardly any discernable downward trend. This may be clearly seen from figures 3 and 4.

The reasons for high energy consumption in the Indian steel industry may be better understood by comparison of the energy consumed in different shops of an Indian steel plant with that of a developed country. Figure 5 shows the comparison between the energy usage in a typical Indian steel plant during 1981-82 with that in a steel plant in Japan during 1975-76. The following observations are made:

(a) Specific energy consumption in the Indian steel plant is about twice that of the Japanese steel plant.

(b) In both cases about 72% of the energy consumed is upto the ironmaking stage.

(c) The fuel utilisation efficiency in the steelmaking and reheat furnaces is poor in the Indian steel plants. Consequently, the specific energy consumption in these areas is roughly twice that in the Japanese steel plant.

## 4. Main Reasons for the High Energy Consumption

An analysis of the operating parameters of the individual shops brings out the main reasons of the high energy consumption levels in the Indian steel plants. Further, such an analysis is useful in defining potential measures for energy conservation. This has been attempted below for major technological areas namely Coke ovens, Ironmaking, Steelmaking and Soaking pits.

## Iron Zone

### *Coke Ovens*

The major factors contributing to high energy consumption in the coke ovens area are:

*(i) Low coke oven gas yield*

The yield of coke oven gas varies in the Indian steel plants from 230 to 290 Nm³/t of coal charged. The low gas yields are due to coal with high ash content varying from 18-22%, low volatile matter varying from 22-25% (see Table 2) and leakage of gas. In the developed countries gas yields of 320 Nm³/t of coal charged while using a coal charge having an ash content of 8% and volatile matter of 27% have been reported.

*(ii) Bad condition of the ovens*

Bad condition of the ovens results in operational difficulties and high energy consumption.

*(iii) High waste Energy*

Table 3 shows the heat balance for coke ovens in one of the steel plants. It is seen that various heat losses like sensible heat of coke and coke oven gas are about 1.3 × $10^6$ Gcal/year for BSP. This is about 10% of the total input energy in the coke ovens.

### *Blast Furnaces*

It is well known that the spectacular decrease in the coke rates in blast furnace operation in the advanced countries has greatly contributed to energy conservation. Figure 6 shows the trend of the coke rates in Japan and the main steps taken to lower coke rates to less than 450 kg/thm and increase productivity. In the Indian steel plants the following factors are mainly responsible for the high coke rates (730 1150 kg/thm).

*High ash content of coke*

Figure 7 shows the ash content of coke in the SAIL steel plants from 1972-73 to 1983-84. It is seen that the ash content in the coke varies between 25 and 29%. In the developed countries the coke:ash is as low as 8-10%. Higher ash in the coke contributes to increased slag volume in blast furnace operation and consequently higher coke rates and lower productivity.

*Poor strength of coke*

Strength of the coke used in the Indian blast furnaces is rather low. The values of $M_{10}$-an index of the abrasion resistance of coke are rather high compared to that of the coke used in the advanced countries. Table 4 gives the data on the coke strength ($M_{10}$).

Lower strength of the coke results in the high generation of fines in the blast furnace operation. Consequently acceptance of blast is lower, productivity is lower and coke rates are higher.

*Low Sinster in burden*

The level of sinter usage in the Indian blast furnaces from 1972-73 to 1983-84 is shown in Figure 7. The use of sinter has a direct effect on the coke rates. Increase in the percentage of quality sinter in the burden decreases the coke rates considerably. In the advanced countries, sinter constitutes about 80-95% of the blast furnace burden.

*High Raw Limestone & Dolomite in the burden*

In the advanced countries the amount of raw limestone/dolomite added in the modern blast furnace burden is 5-10 kg/thm. In some of the SAIL steel plants (DSP, IISCO) raw limestone/dolomite addition is very high—about 350-550 kg/thm (see Table 4). This results in higher coke rates as the thermal decomposition is highly endothermic.

*Low blast temperature*

Figure 7 shows the data on blast temperature achieved during the period 1972-73 to 1983-84 in the Indian steel plants. The average value of the blast temperature in the Indian steel plants is around 720°C, which is very low as compared to the blast temperature levels of 1100-1350°C achieved in the advanced countries.

*High top pressure*

Super high top pressure in blast furnaces (2.5-3.5 atmospheres gage) is being practiced in the advanced countries for achieving increased productivity and lower coke rates. In India, only Bokaro steel plant is practicing moderate top pressure of about 1.4-1.5 atmosphere.

*Unstable blast furnace operation*

Unstable operation of blast furnaces is caused by:

(a) Unstable thermal regime on account of inconsistency in the quality of input materials

(b) Excessive fines in the iron ore and sinter and improper burden distribution

(c) Problems in availability of input materials

(d) Logistic problems related to tapping of hot metal system with evaporative water cooling and insulating blocks having an inner layer of ceramic fibre.

(vi) Introduction of economically justified waste heat recovery systems requiring moderate investments.

*(c) Modernisation Measures*

These are generally capital intensive in nature. These measures are vital for efficient plant operation and failure to modernise the plant at the right time results in steep deterioration in the plant output.

Some of the modernisation measures that may be adopted are:

- stamp charging of coal charge;
- partial briquetting of coal charge;
- modernisation of the existing sinter plants and installation of new sinter plants;
- intensification of blast furnaces;
- replacement of open hearth furnaces by oxygen steelmaking converters;
- large scale adoption of continuous casting;
- introduction of walking beam/walking bottom furnaces;
- modernisation of rolling mills;
- introduction of computer control systems in all the shops,
- introduction of waste energy recovery processes like coke dry quenching, heat-recovery systems in sinter plant, power generation ~~using~~ blast ~~furnace~~ top gas pressure.

## 9. Energy Conservation Efforts of SAIL

In order to give a new impetus to the energy conservation efforts of SAIL, a report consisting of plant-wise energy conservation plans was prepared by SAIL in March, 1983. A brief list of the three categories of energy conservation measures included in the energy conservation plans of the SAIL steel plants is given-in Annexure-I. The implementation of these measures has been taken up by the Task Force for Energy Conservation in individual shops of the steel plants. The progress of implementation of these measures is being monitored at the plant-level as well as at the Corporate level. Some of the short-term measures are being routinely followed. A number of medium-term measures are in progress. Long-term measures are planned to be introduced as part of the modernisation programmes.

Mention may be made of some of the technologies developed through R&D efforts in our plants contributing to energy conversation.

*Lime Dust Injection*

The technology of lime dust injection through tuyeres of blast furnace has been developed on the small scale at Kalinga Iron Works. Lime has been injected on continuous basis at the rate of 30 to 40 kg. per tonne of hot metal in blast furnace No. 3. The increse in productivity is in the range of 11-15% and decrease in coke rate 6-11%. This technology is presently being upscaled at DSP where lime dust at the rate of 100 kg. per tonne of hot metal will be injected in blast furnace No. 1. The demonstration plant is under construction and is expected to be commissioned by the end of this year.

*Use of high basicity sinter*

It is a well established fact that if the raw lime stone charging in blast furnace is avoided by charging of the flux through sinter, substantial benefits can be achieved with respect to increase in productivity and decrease in coke rate in blast furnace. This objective in our steel plants can be achieved by charging either high percentage of the sinter burden of lower basicity or lower percentage of sinter in the burden of higher basicity. The trials at BSP have been carried out on both the above alternatives by eliminating 100 kg. per tonne of hot metal of lime stone through use of higher basic sinter. The increase in productivity was of the order of 5-6% and decrease in coke rate about 4-6%.

*Use of extended hood practice in the sintering*

The RDCIS design of extended hood has been implemented in sintering plant No. 2 in BSP. This modification will result in lower energy consumption and higher productivity of sintering machine.

*Use of Coal Bonded Pellets in Blast Furnaces*

The technology of coal bonded pellets eliminates use of fuel oil as required in conventional heat hardening pelletisation process. Trials with coal bonded pellets have been carried out at KIW using 25 to 30% pellets in blast furnace burden. The benefits with respect to increase in productivity and decrease in coke rate were of the order of 7-11%. The technology is now being upscaled for blast furnaces of IISCO.

*External Desiliconisation and Desulphurisation of hot metal*

The desiliconisation practice has been modified at DSP to achieve the higher degree of desiliconisation by increasing the lime stone consumption from 250 kg. to 1000 kg. per ladle. The drop in silicon content of hot metal was increased from 0.4 to 0.8%. The implementation of this technology will help in decrease in the lime consumption in open hearths and also an increase in productivity by reducing the duration of heat. RDCIS has also established the practice of desulphurisation of hot metal using the indigenously available cheaper reagent like lime and soda ash. The adaptation of this practice will help in running the blast furnaces on low slag basicity thus will help in increasing the productivity and decreasing the coke rate.

*Optimum thermal and lancing regime in the open hearth furnaces*

Implementation of this project at BSP has resulted in 15% saving in specific heat consumption. Similar benefits have also been achieved at DSP open hearth furnaces.

## 6. Steelmaking

The high energy consumption in the area of steelmaking can be mainly attributed to:

*(i) High Ratio of open hearth steelmaking to oxygen steelmaking*
In the developed countries the steelmaking is mainly through oxygen steelmaking route, while in India over 50% of the steel is produced through the open hearth furnace route (Table 5). Open hearth steelmaking process is highly energy intensive as it is a slow process.

*(ii) High specific fuel consumption*
The high specific fuel consumption in the open hearth furnaces is contributed by unstable operation of the furnaces, low productivity and improper combustion control.

*(iii) Conventional Ingot casting route*
In SAIL steel plants almost 100% of the steel is cast through ingot casting route. In modern steel plants almost 100% of the steel is cast through the continuous casting route where the yield is high and one reheating operation is eliminated.

## 7. Rolling Mills

The following factors contribute to high energy consumption in the area of rolling mills:

*(i) Obsolete combustion systems in furnaces*
The combustion systems in the furnaces of primary and finishing rolling mills e.g. soaking pits, reheating furnaces, etc. are quite old in the Indian steel plants. In oil firing burner systems poor atomization, chocking of burner tips and leakage of oil etc. are common leading to high energy consumption.

*(ii) High track time*
Track time of ingots is one of the major factors contributing to very high energy consumption in the soaking pits. The average track time in the Indian steel plants varies between 2.5 hours to 4.5 hours. By reducing the track time through extensive use of modern communication facilities for close monitoring and control and modernising auxiliary facilities like charging, discharging etc., Japanese steel plants are able to achieve a specific fuel consumption of about 0.15 Gcal/t whereas in the Indian steel plants it varies from 0.25 to 0.5 Gcal/t.

*(iii) High heat losses through cooling water/refractories*
The heat losses through the cooling water and furnace structure account for nearly 30-32% of the heat supplied. This is due to obsolete design of cooling water systems in reheating furnaces and use of poor quality of insulation material in the Indian steel plants.

*(iv) Unstable Mill operation*
Unstable mill operation is mainly due to the prevailing obsolescence of equipment. This results in difficulties in synchronising the heating operations and the rolling operations.

## 8. Categories of Energy Conservation Measures

Systematic and sustained efforts are required to bring down the level of energy consumption in the steel plants. The energy conservation measures can be broadly categorised as:

(a) Operational improvements
(b) Equipment improvements
(c) Modernisation measures

*(a) Operational Improvements*
For evolving and implementing energy conservation plans in the steel plants, it is imperative to give due importance to the matters related to
—improvement in operations technology
—improvement in administrative measures
These steps need hardly any capital investment, but have to be followed on a continuous, routine basis. Some of the examples of improving operational aspects are:

(i) To minimise leakage of oil, air, steam etc.
(ii) To analyse the fuel gases regularly for maintaining appropriate air-fuel ratio
(iii) To maintain proper quality and size of input raw material
(iv) To rigidly follow thermal regimes of furnaces
(v) To operate optimum number of furnaces

*(b) Equipment Improvements*
The second category of the measures is equipment improvement. These require marginal investment and the return is quite high. Some examples are:

(i) Insulation of cold blast main;
(ii) Minimising leakages of hot blast;
(iii) Improvement in combustion systems. This requires replacement of existing burners with those of modern design like ceramic burners in blast furnace stoves, high velocity burners in soaking pits, flat flame burners in reheating furnaces etc.;
(iv) Use of ceramic fibre insulation in the furnaces. This would reduce the heat loss from the furnaces to an extent of 5-7%;
(v) Modification of water-cooled skids in the reheating furnaces. This is one of the important measures to bring down the energy consumption in the furnaces as heat losses through an uninsulated skid system can account for as much as 30% of the heat supplied to the furnaces. In modern furnaces the trend is to use skid

*Oxygen assisted melting in electric arc furnace*

Implementation of this project at ASP has resulted in reduction in melting time by about 20 minutes and reduction in power consumption by 80-100 KWH per tonne.

*Oxygen enrichment of combustion air in soaking pit*

This practice has been introduced in RSP and DSP and has resulted in saving of fuel consumption by about 10-12%.

*Use of ceramic fibre seal in soaking pits*

This project has been implemented on trial basis in the soaking pits at BSL. The ingot heating rate is faster and heat utilisation is better as indicated by the lower heat consumption.

*Modified combustion system in reheating furnace at IISCO*

The new combustion design system has given 16 to 20% reduction in specific heat consumption for structural mill and 21% reduction in light structural mill.

## 10. Discussion and Recommendations

Steel industry is highly energy intensive, since the various industrial operations have to be performed at high temperature conditions. It hardly needs to be emphasised that all other conditions remaining constant, the extent of energy conservation measures directly reflects on the profitability of a steel industry.

As the follow up of the last paper on upgradation of technology, this paper deals with more specifics in the area of energy scenario.

The most important observation is that the specific energy consumption in the Indian steel plants is about twice that of steel plants in other developed countries like Japan. The differential is of the same order even with other steel producing countries who are comparatively newcomers in the area like South Korea and Brazil.

It is observed that in our steel plants the rate of increase in saleable steel production between 1970-71 to 1983-84 is significantly lower than the rate of increase in total energy consumption. For 60% increase in saleable steel production during the last 10 years, increase in energy consumption is about 90%. In other words, specific energy consumption figures have been increasing Even the consumption of the high value petroleum fuels during the same period has increased roughly by about 80%.

Various kinds and quality of energy inputs in different plants of SAIL and relative energy consumption figures in all the integrated steel plants inclusive of TISCO are given The first apparent anomaly is needed to be highlighted. Consistently, the lowest energy consumption per tonne of finished steel has been in BSP, a fully open-hearth based steel plants till now, and not in the plants using oxygen process converter. While necessary correction due to differential product-mix as well as differential quality of raw materials can be made the fact remains that the obvious advantage of oxygen steelmaking process over open-hearth in energy front has been upset by possibly better technology discipline and development and adaptation of more energy efficiency measures at BSP through inhouse R&D efforts particularly in iron and steelmaking zone.

It is also necessary to observe that during the period 1976-77 to 1983-84, fuel bill has increased in SAIL from a level of Rs. 240 crores to Rs. 860 crores even though the level of saleable steel production has somewhat decreased. It is worth mentioning that during the period, the rate of increase in steel price has been substantially lower.

Between 1950s and 1980s, all the other steel producing countries have reduced their specific energy consumption figures by around 50%. In fact in the 1950s and early 1960s, our energy consumption figures were equivalent to the same as in other steel plants abroad, which has, however, marginally increased during this period, while elsewhere the same has been halved.

After the said situation analysis, the causes of differential energy consumption have been highlighted. Since 80 to 90% of the total energy input to steel plants is through coal, primarily coking coal, the coal quality deterioration has the most significant effect on specific energy consumption. Ash content of coking coal has been steadily increasing from 17% to 22%. The effect of even marginal increase in ash content at such high level is disastrous in terms of exponential increase in coke rate and reduction in productivity in blast furnace and also deterioration in quality of hot metal thereby affecting sharply on steel making practice, the yield of products and increase in energy consumption in down stream areas with a multiplier effect. In this area, the steel plants are fighting a losing battle. While ash content of coking coal for economic production of iron has been decreasing from around 17% to 6 to 7% in Japan and elsewhere, with corresponding improvement in total energy efficiency, the ash content in Indian coking coal has been increasing and has now come to an alarming level. In fact, acceptable quality of coking coal for economic production of iron is no longer available in India, the resources can only be used for blended purposes with imported high caking index and low ash coking coal. Planners have to concentrate on this single largest constraint directly affecting techno-economic level of our steel industry.

While between 60 to 70% performance differentials can be attributed to the said inherent problems, the other major causes are also required to be highlighted. These are—gradual deterioration of technology discipline, equipment hardware constraints, inadequate R&D inputs to consistently improve the state of art, and introduction of indigenous technologies and lack of systematic, planned and in-time refurbishing and debottlenecking and technology modernisation efforts.

Improved technology discipline in our plants can sharply reduce specific energy consumption. Introduction of decentralised shop floor/profit centre based reward and punishment schemes are required to be evolved and institutionalised. Both in the capitalist and socialist countries such decentralised, reward and punishment schemes have given best results in energy efficiency front. Incidentally in this area we are going back in time in terms of upward centralisation of authority through multiple, horizontal and vertical channels upto BPE.

Commercial adaptation of established R&D outputs is also an area needing more attention. R&D projects involving marginal or low investments with a potential to improve in state-of-art are established through controlled experiments in the plants with tangible results in improving energy efficiency. However, the same is often not commercialised in sustained manner due to extraneous and often human problems. R&D projects involving the total cycle from concept to commercialisation also get delayed at the stage of introduction of commercial facilities both in investment decision making stage as well as project construction stage. Appropriate system and management decisions are called for.

For improvement of performance in energy front priority has to be given on introduction of imported software based technology packages through R&D and designs and engineering organisations for appropriate adaptation and further improvement of the imported technologies. As mentioned in the earlier paper, a National Standing Committee should identify targets of energy consumption in various technology areas which are to be made mandatory within specific timeframe.

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Table-1: Energy Inputs to Individual Steel Plants During 1983-84

| Item | Unit | BSP | BSL | DSP | IISCO | RSP | Total SAIL Plants |
|---|---|---|---|---|---|---|---|
| Coking coal | X $10^6$ t | 2.944 | 3.497 | 1.472 | 1.650 | 1.681 | 11.244 |
| Steam coal | X $10^6$ t | 0.516 | 0.743 | 0.260 | 0.495 | 0.241 | 2.255 |
| Petroleum fuels | X $10^3$ t | 9.990 | 6.020 | 98.50 | 22.60 | 94.470 | 231.61 |
| Purchased electricity | X $10^6$ MWH | 0.632 | 0.810 | 0.293 | 0.128 | 0.518 | 2.381 |
| Total energy input | X $10^6$ Gcal | 22.71 | 28.03 | 11.77 | 13.79 | 13.38 | 89.68 |
| Steel production | X $10^6$ ingot | 1.837 | 1.681 | 0.806 | 0.592 | 1.088 | 6 0[illegible] |
|  | X $10^6$ Saleable | 1.538 | 1.288 | 0.602 | 0.444 | 0.862 | 4.738 |

### Table-2: Ash Content and Volatile Matter in the Coal Blends of Indian Plants During 1976-77 to 1982-83

| Sl. No. | Plant | | Year | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | 1976-77 | 1977-78 | 1978-79 | 1979-80 | 1980-81 | 1981-82 | 1982-83 |
| 1. | BSP | | | | | | | | |
| | Ash | % | 18.99 | 19.84 | 20.20 | 19.60 | 20.10 | 19.70 | 18.70 |
| | VM | % | 24.00 | 24.90 | 24.70 | 24.40 | 23.60 | 23.70 | 23.10 |
| 2 | RSP | | | | | | | | |
| | Ash | % | 18.91 | 19.05 | 18.95 | 18.64 | 19.41 | 18.87 | 18.52 |
| | VM | % | 24.05 | 25.10 | 25.18 | 24.86 | 24.12 | 23.94 | 23.10 |
| 3. | DSP | | | | | | | | |
| | Ash | % | 20.22 | 20.44 | 21.12 | 22.69 | 21.96 | 22.13 | 21.78 |
| | VM | % | 23.63 | 23.53 | 23.46 | 22.57 | 22.90 | 21.94 | 21.92 |
| 4 | BSL | | | | | | | | |
| | Ash | % | 19.83 | 21.38 | 20.45 | 21.18 | 21.81 | 21.05 | 20.64 |
| | VM | % | 24.31 | 23.85 | 23.85 | 23.72 | 23.47 | 23.22 | 22.81 |
| 5 | IISCO | | | | | | | | |
| | Ash | % | 19.93 | 20.20 | 20.83 | 21.41 | 21.71 | 22.20 | 21.92 |
| | VM | % | 25.58 | 25.03 | 25.05 | 24.92 | 24.92 | 24.69 | 24.46 |

### Table-3: Coke Ovens Heat Balance

| Sl. No. | Item | Unit | Material input/ output value | Energy equivalent, $10^6$ Gcal/yr | |
|---|---|---|---|---|---|
| 1.0 | Input | | | | |
| 1.1 | Coking coal | X $10^6$ t | 1.93 | 12.54 | 89.8 |
| 1.2 | CO gas | X $10^9$ Nm$^3$ | 0.07 | 0.26 | 1.9 |
| 1.3 | BF gas | X $10^9$ Nm$^3$ | 0.97 | 0.94 | 6.7 |
| 1.4 | Air preheat | X $10^9$ Nm$^3$ | 1.07 | 0.22 | 1.6 |
| | | | | 13.96 | 100.0 |
| 2.0 | Output | | | | |
| 2.1 | Coke (potential) | X $10^6$ t | 1.50 | 10.10 | 72.3 |
| 2.2 | Benzol (potential) | | | 0.04 | 0.3 |
| 2.3 | Tar (Potential) | X $10^6$ t | 0.05 | 0.47 | 3.4 |
| 2.4 | CO gas (potential) | X $10^9$ Nm$^3$ | 0.48 | 2.00 | 14.3 |
| 2.5 | Losses | | | 1.35 | 9.7 |
| | | | | 13.96 | 100.0 |
| | Break-up of losses | | | | |
| 2.5.1 | Coke sensible heat | | | 0.54 | |
| 2.5.2 | Dry gas sensible heat | | | 0.10 | |
| 2.5.3 | Benzol & tar sensible heat | | | 0.01 | |
| 2.5.4 | Waste gas heat | | | 0.30 | |
| 2.5.5 | Others | | | 0.40 | |

Table-4: $M_{10}$ Value and Limestone Consumption in Blast Furnace During the Period 1972-73 to 1983-84

| Item | Plant | 72-73 | 73-74 | 74-75 | 75-76 | 76-77 | 77-78 | 78-79 | 79-80 | 80-81 | 81-82 | 82-83 | 83-84 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $M_{10}$ Value | BSP | | | | | | | 11 | 12 | 13 | 12 | 13 | 15 |
| | RSP | | | | | | | 10 | 10 | 11 | 10 | 10 | 11 |
| | DSP | 14.9 | 14.9 | 14.0 | 16.5 | 13.9 | 14.4 | 15 | 16 | 15 | 15 | 15 | 18 |
| | BSL | | 9.9 | 8.8 | 9.9 | 9.9 | 10 | 10 | 11 | 13 | 13 | 13 | 13 |
| | IISCO | | | | | | | 17 | 17 | 17 | 18 | 18 | 17 |
| Raw Limestone + Dolomite kg/thm | BSP | 222 | 206 | 179 | 179 | 171 | 190 | 185 | 168 | 116 | 110 | 42 | 60 |
| | RSP | 369 | 408 | 288 | 235 | 232 | 309 | 288 | 209 | 284 | 312 | 291 | 190 |
| | DSP | 368 | 363 | 456 | 400 | 394 | 351 | 359 | 347 | 343 | 386 | 302 | 380 |
| | BSL | 124 | 75 | 48 | 33 | 52 | 64 | 108 | 195 | 174 | 125 | 126 | 100 |
| | IISCO | 428 | 480 | 480 | 474 | 460 | 495 | 494 | 578 | 579 | 608 | 559 | 560 |
| | TISCO | 288 | 241 | 242 | 222 | 202 | 162 | 82 | 65 | 52 | 82 | | |

Table-5: Steel Production Data Through Open Hearth Furnaces and LD Converters Druing the Period 1976-77 to 1982-83 in SAIL Steel Plants

| Year | Steel through Open Hearth X $10^6$ tonnes | Steel through LD Converters X $10^6$ tonnes | % Open Hearth Steel |
|---|---|---|---|
| 1976-77 | 4.361 | 2.158 | 66.90 |
| 1977-78 | 4.423 | 2.033 | 68.51 |
| 1978-79 | 4.070 | 2.217 | 64.73 |
| 1979-80 | 3.856 | 2.393 | 61.71 |
| 1980-81 | 3.659 | 1.820 | 66.78 |
| 1981-82 | 3.893 | 2.747 | 58.63 |
| 1982-83 | 3.927 | 2.752 | 56.91 |

**Annexure-I**

## Category-I: Operational Improvement

*(i) Coke Ovens*

- improvements in operating practices—full charging of ovens, proper sealing of oven doors to reduce door leakage and brazing
- to maintain thermal regime and control of heating
- regular cleaning of regenerators
- to maintain constant $O_2$ in flue gas

*(ii) Sinter Plant*

- proper maintenance and cleaning of fuel line to maintain the required flow to all the strands
- proper de-dusting to be ensured to facilitate better working condition
- regular air-gas ratio control
- proper quality and sizing of input materials
- rectification of air leakage in the suction line of blower

*(iii) Blast Furnaces*

- better sizing and screening of input materials
- higher usage of sinter
- cleaning of the burners and chequers of the stove
- proper operational heating and control cycles of the stove
- minimising air loss by proper maintenance of cold and hot blast lines
- lower limestone in the burden either by increasing the sinter use or by using the higher basicity sinter.

*(iv) Steel Melting Shop*

- to work out optimal thermal regimes in open hearth furnaces taking into consideration the technological parameters and condition of the furnaces.
- to reduce constant heat losses through cooling water, walls, openings and flue, intensification of O.H. processes such as by oxygen lancing or higher heat load.
- regular flue gas analysis to be done for combustion control as well as to study air infiltration through regenerator and to take necessary corrective actions
- cleaning of regenerator channels periodically to maintain its higher efficiency
- operation, mechanical and electrical delays to be minimised.

*(v) Soaking Pits*

- to reduce heat losses from ingots to ambient by lowering track time; using optimum time of ingots inside and outside the mold before charging
- proper scheduling of charging and discharging of soaking pits to be done in order to ensure readiness of ingots
- to ensure air tight operation of the pits by proper sand sealing of covers, skirt plates etc.

*(vi) Reheating Furnaces*

- all discharge doors, charging doors and inspection doors to be kept functioning properly
- percentage oxygen in the flue gas is to be maintained around 1-2%
- all furnace pressure controls are to be in perfect working condition
- to use optimal thermal regimes for various sections rolled.

*(vii) Power Plant*

- to ensure availability of better quality coal in respect of ash content
- to ensure better wagon availability for removal of ash from boilers
- to plug all steam and air leakages to reduce steam consumption in turbo blowers
- to try the use of steam through wind box of boilers to avoid clinker formation
- to keep the coolers of turbo compressors in proper working condition
- to analyse the coal unburnt carbon in the cinder regularly.

## Category-II: Equipment Improvement

*i) Iron-Making*

- insulation of cold blast line from turbo blower to the blast furnance stoves
- elimination of leakages of cold and hot blast
- modification of gas pipeline diameter to increase the fuel firing rate
- to increase blower capacity of combustion air in the sinter plant
- close circuit flux crushing to control lime fineness
- screening of sinter near skip pit

*ii) Steel Making*

OH Furnace

- modification in burners for improved firing of CTF
- Introduction of double oxygen lancing in OH Furnaces

*iii) Soaking Pits*

- burner modification
- replacement of blower to ensure required suction
- introduction of ceramic ceiling of the pit cover
- modification in burner design
- burner port modification
- flue arch modification

*iv) Reheating Furnaces*

- introduction of flat flame burners
- modification of skid insulation
- modification of burners

*v) Power Plant*

- modification in combustion air distribution for grate coal firing
- modification of BF gas burners

## Category-III: Modernisation

*i) Iron Making*

- installation of sinter machine for augmenting sinter usage in the blast furnaces
- coal dust injection
- lime dust injection
- dry type top pressure recovery turbine
- introduction of ceramic burners in the stove
- preheating of combustion air of the stove
- coke dry quenching sytems
- case heat recovery through sinter cooling

*ii) Steel Making*

- installation of LD converters
- installation of continuous casting euipment
- top and bottom blowing for BOF
- recovery of LD gas incorporating suppressed combustion system

*iii) Soaking Pits*

- automatic combustion control for soaking pit
- computerisation of operation

*iv) Reheating Furnaces*

- automatic combustion control
- computerisation of furnace control
- avaporative cooling of skids
- introduction of ceramic fibre blocks

*v) Utility Plants & Others*

- introduction of fluidized bed combustion in the power plant boiler
- firing of COM and/or CWM to reduce fuel oil consumption in the power plant
- introduction of energy supply demand system
- automatic control in oxygen-plant

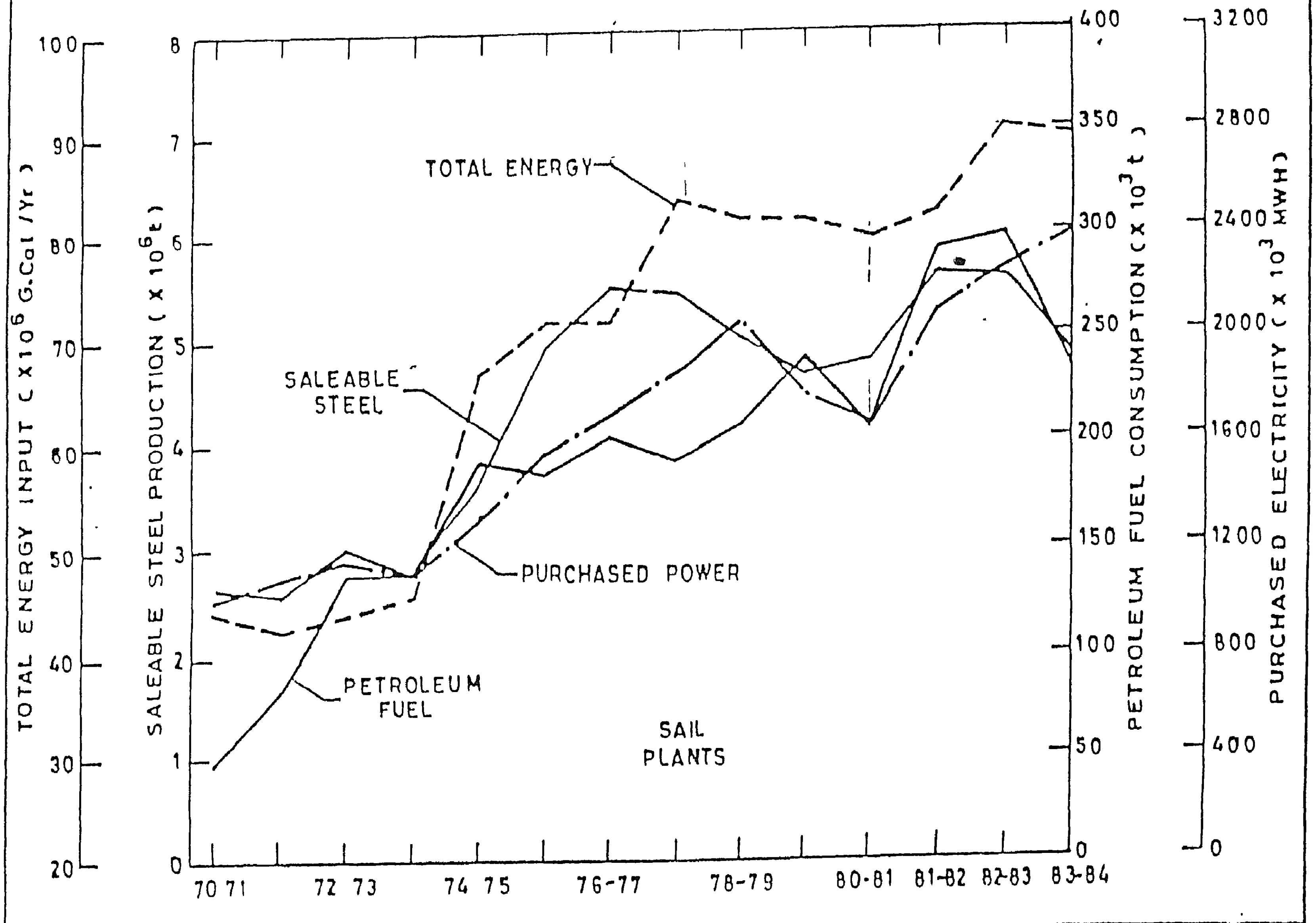


FIG. 1

YEARWISE ENERGY CONSUMPTION DATA

RDCIS

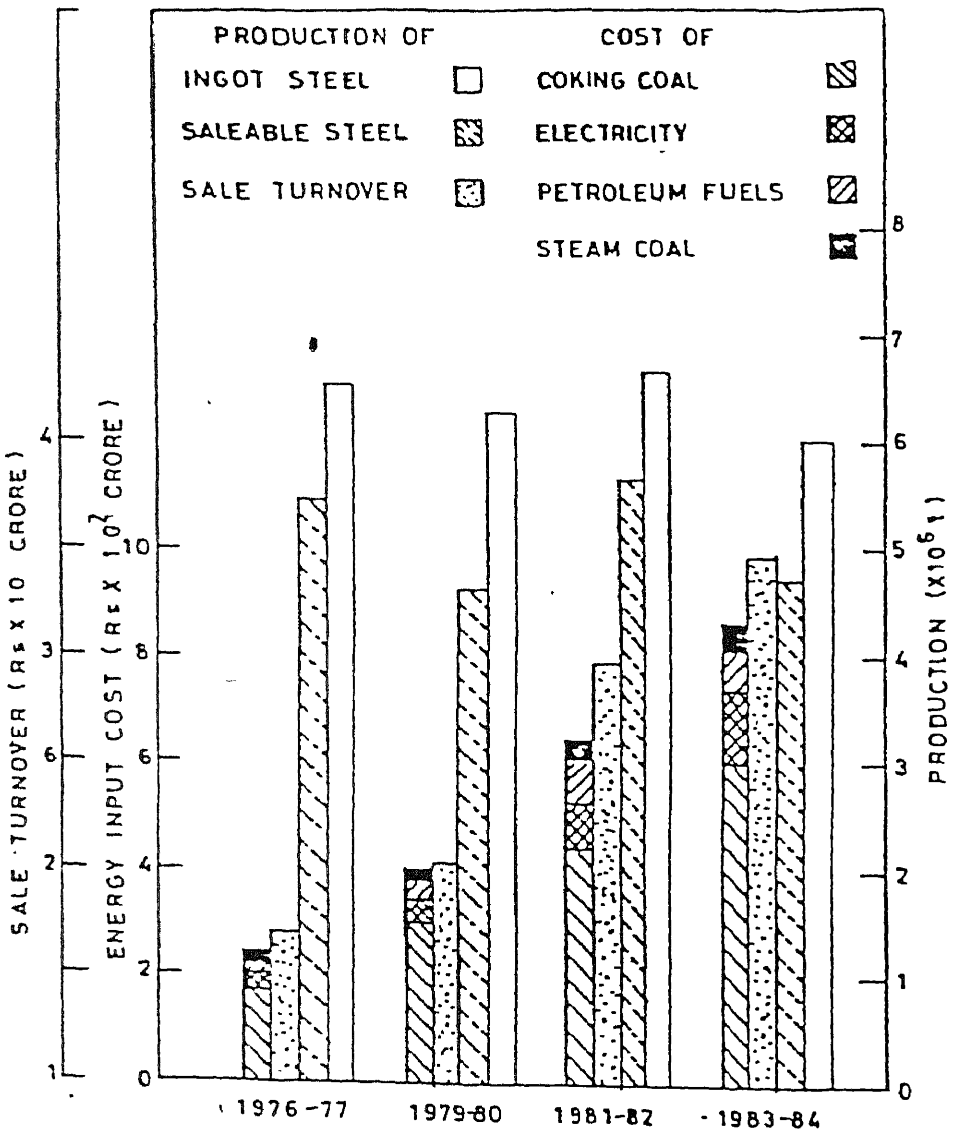


FIG-2

INPUT ENERGY COST (SAIL)

RDCIS

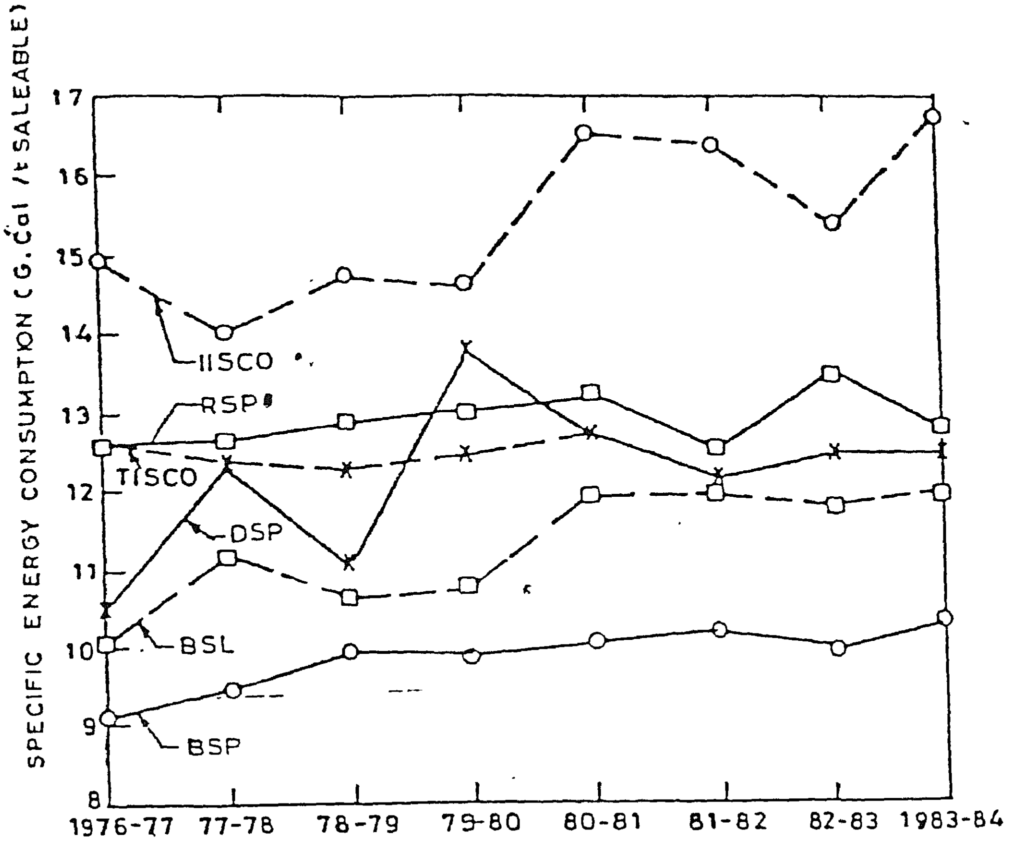


FIG. 3

SPECIFIC ENERGY CONSUMPTION DATA (INDIA)

RDCIS

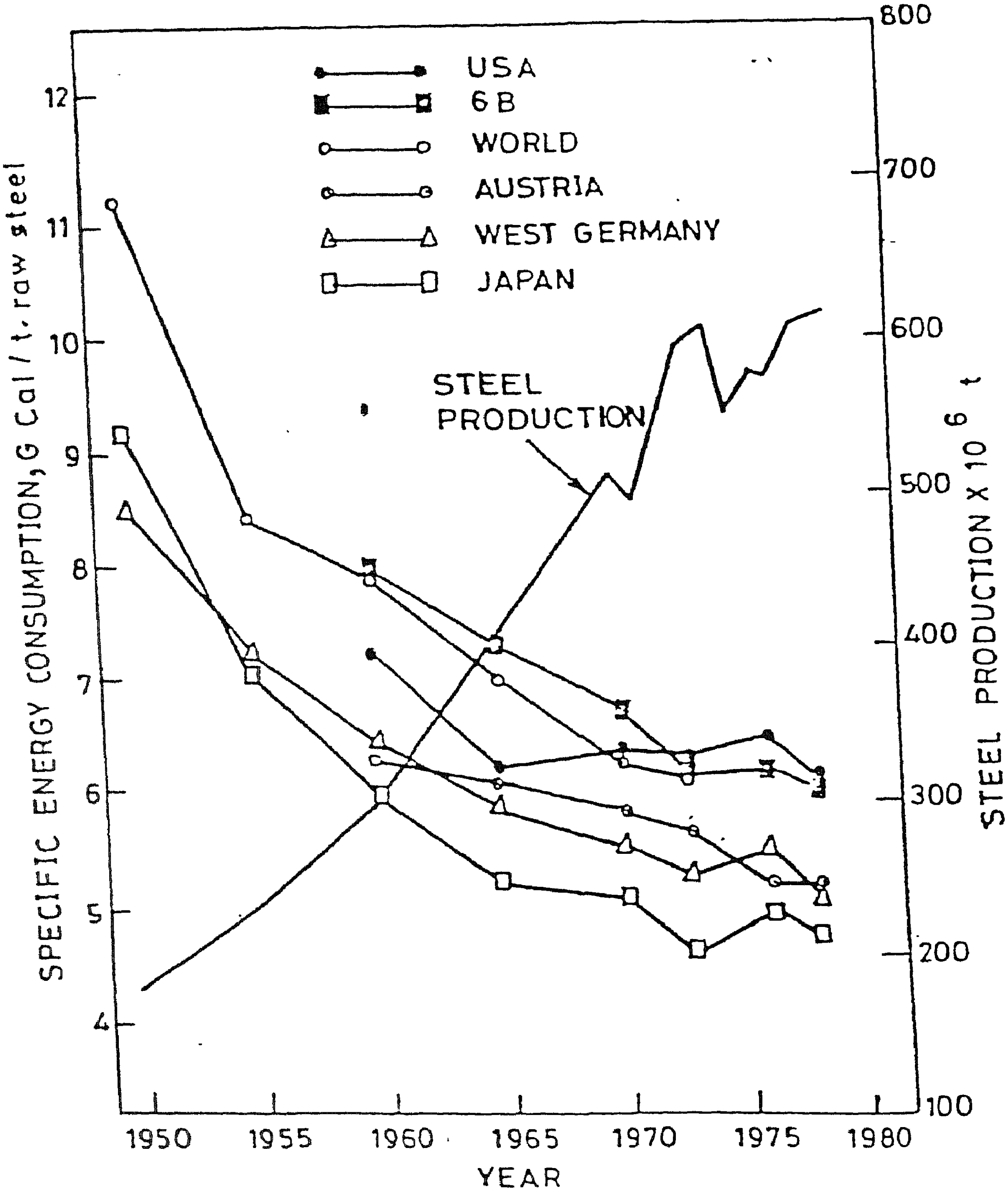
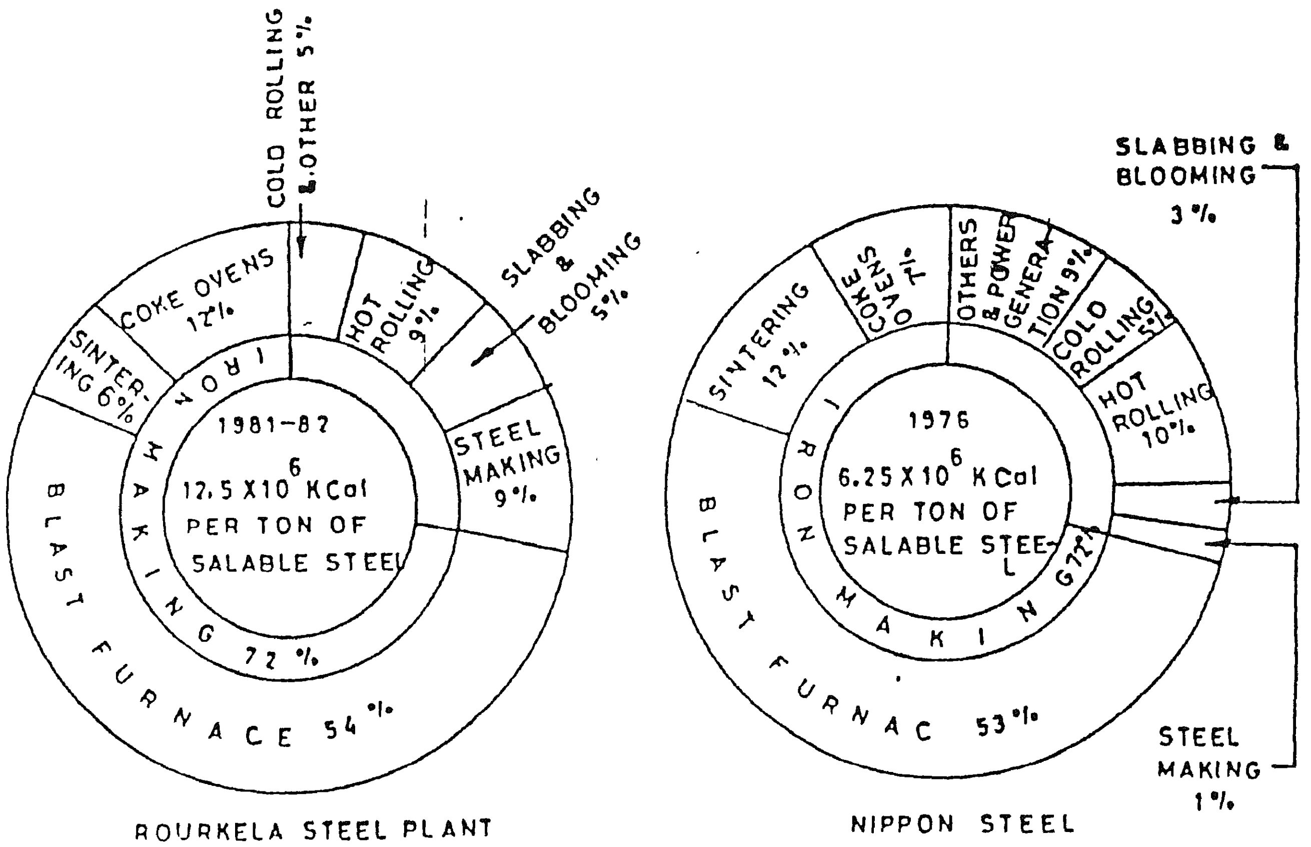


FIG. 4 SPECIFIC ENERGY CONSUMPTION – OTHER COUNTRIES.

RDCIS

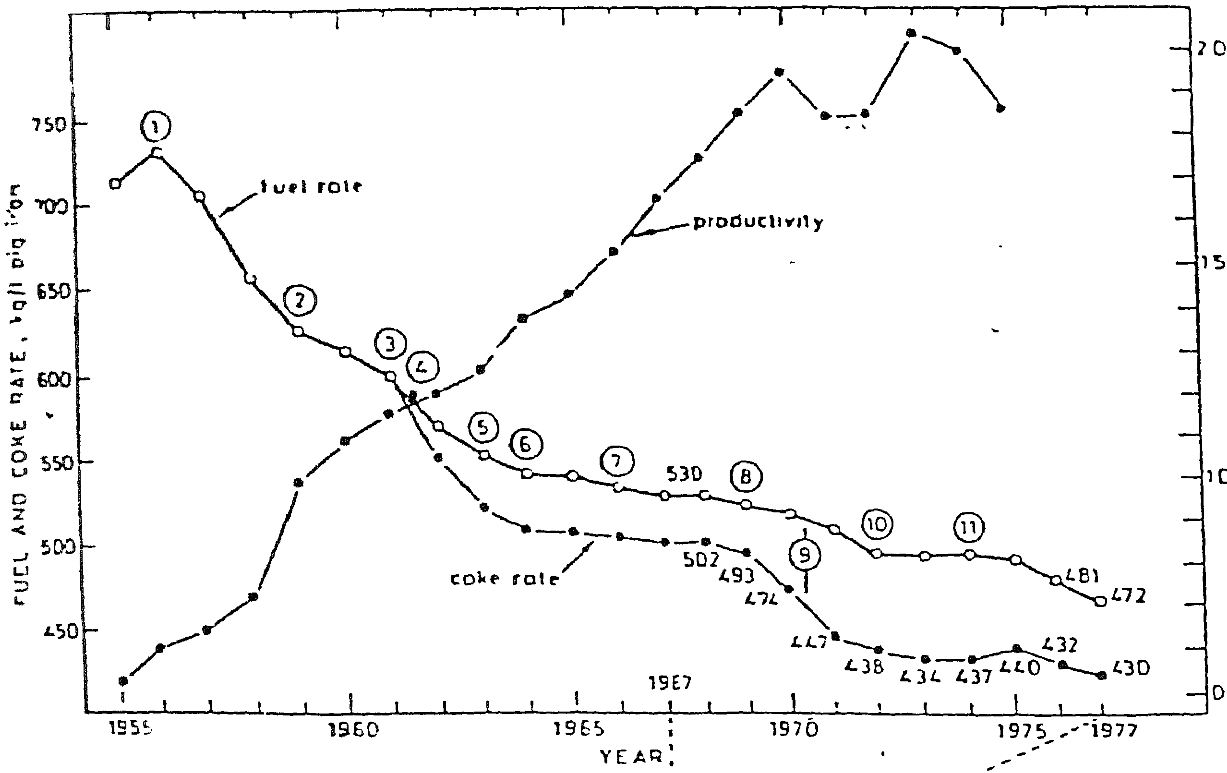


ROURKELA STEEL PLANT

NIPPON STEEL

FIG. 5 COMPARISON OF ENERGY DATA

RDCIS



① use of high self-fluxing sinter
② oxygen enrichment of blast
③ fuel injection and high temperature blast
④ high top pressure operation
⑤ use of imported pellet
⑥ spread of fuel injection
⑦ construction of high temperature stoves
⑧ super-high top pressure
⑨ increase of fuel injection
⑩ control of burden distribution
⑪ dehumidification

| | 1967 | 1977 | Fuel rate, kg/t HM |
|---|---|---|---|
| ① | 55.0% | 75.7% | 19 |
| ⑤ | 12.0% | 10.7% | |
| ⑦ | 990°C | 1203°C | 21 |
| ⑪ | 25 g/Nm³ | 13 g/Nm³ | 8 |
| slag ratio, kg/t HM | | | |
| | 285 | 301 | +5 |
| coke ash, % | | | |
| | 9.8 | 11.1 | +13 |
| low Si in hot metal | | | 28 |
| ore sizing | | | |
| better furnace control | | | |
| ⑧ | — | 1530 kg/cm² | |
| others | | | |
| fuel rate, kg/t HM | | | |
| | 530 | 472 | 58 |

ig. 6 Trend of productivity, fuel rate, and coke rate of blast furnaces in Japan

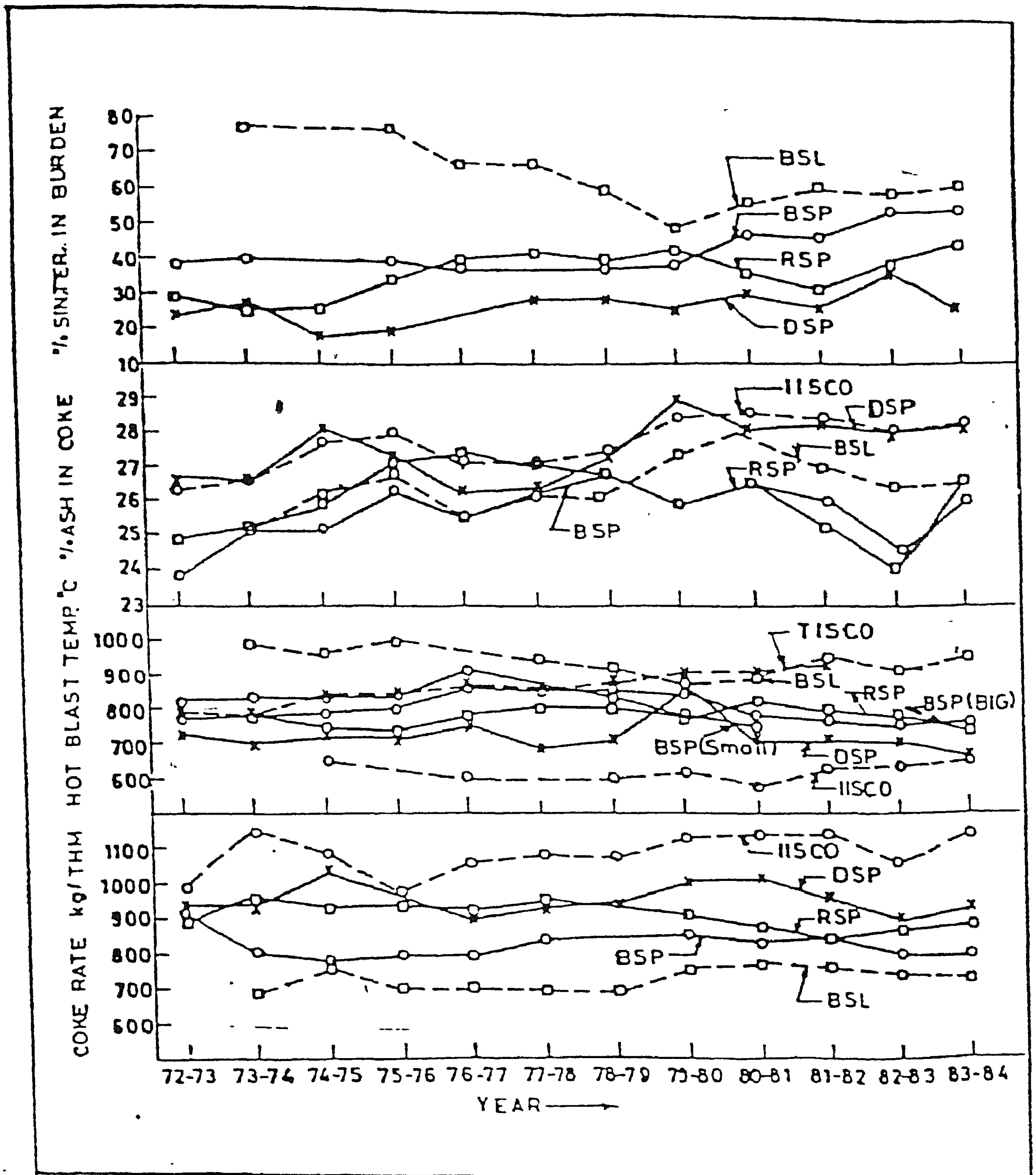


FIG 7

IMPORTANT PARAMETERS IN BLAST FURNACES

RDCIS

THERMAX

# CASE STUDIES
# IN
# ENERGY CONSERVATION

PREPARED
FOR
SEMINAR ON ENERGY CONSERVATION

BY

HEAT RECOVERY DIVISION
THERMAX PRIVATE LIMITED.

- Heat Recovery systems for thermic fluid heating, water heating and steam generation, could be tailor made so that performance of D.G. set is not affected in any way.

- Once a captive power source which was cheaper than grid power was installed, continuous operation of critical equipment could be ebsured at all times, irrespective of power cuts, both scheduled as well as unscheduled.

Once these facts were brought forth, decision in favour of installing heat recovery system was straight forward. Heat was decided to be recovered in form of steam, by installing a custom-built, two drum, natural circulation water tube boiler and a finned economiser. The boiler was designed for recovering around 24 lac Kcal per hour, which is equivalent to around 3650 Kg/hr steam (F&A 100°C)

Now, when the system has been working sucessfully for 6 months, Management of Modipon considers their decision to adopt co-generation system, a wise one and have even decided to go-ahead with same configuration in 2nd phase of D.G. Set capacity expansion.

## CASE - 1 INSTALLATION OF HEAT RECOVERY SYSTEM ON D.G. SET AT MODIPON, U.P.

Chronic power shortage has badly afflicted major industries in North India. Modipon Ltd., one such unit, was losing Rs. 2.5 crores per year on this account/ it was forced to install a / till captive power generation system. Steam turbine based co-generation systems were not considered due to huge financial outlays, long gestations and unmatched power - steam requirements.

Simplest solution, therefore was installation of a D.G. set and that's how the project was launched. Resources were limited and hence initial instructions were to procure bareat minimum of equipment.

The project department of Modipon however pointed out that a D.G. Set heat recovery system would cost only 7-10% extra and could save Rs. 30 lacs per year on operation cost.

More detailed analysis was asked for and figures which emerged revealed:

- By heat recovery system, cost of power from D.G. set could be reduced by 12-15%.
- Even with low grid power cost prevailing at that time continuous operation of D.G. Set with heat recovery, would save money for the company, rather than increase the cost of operations as was believed.
- Past trends indicated that the cost advantage for D.G. set with heat recovery, will become even more pronounced with passage of time.
- The company will burn 4000T lees of coal, reducing procurement, storage, handling and ash disposal expenses.

## SALIENT FEATURES OF D.G. SET HEAT RECOVERY SYSTEM INSTALLED AT MODIPON LTD.

### APPLICATION:

| | |
|---|---|
| D.G. Set capacity | - 5.4 M.W. |
| MAKE | - Wartsila |
| Exhaust gas temperature | - 370°C |
| Quantity | - 42624 Kg/hr |
| Steam pressure required in process | - 12.5 $Kg/cm^2g$ |

### SYSTEM DESIGN

| | |
|---|---|
| Total Heat Recovered | - 2421000 Kcal/hr |
| Reduction in exhaust gas temp. | - from 370 to 225°C in boiler<br>225 to 175°C in economiser |
| Steam generation at full load | - 3655 Kg/hr f&A 100°C |
| Total pressure drop on gas side | - 150 mm wc in boiler<br>45 mm wc in economiser |
| Controls provided | - Level transmitter and controller.<br>- pressure transmitter.<br>- level control switches in F.W. tank<br>- Automatic gas by-pass<br>- feed control |

### SAVINGS

| | |
|---|---|
| Cost of power from grid | - Rs. 1.08/kwh |
| Cost of power from DG Set without heat recovery | - Rs. 1.03/kwh |
| Cost of power from DG set with heat recovery | - Rs. 0.91P/kwh |
| Savings in power cost | - Rs. 0.12P/kwh |
| Likely yearly savings | - Rs. 30 lacs/year on 5000 hrs of operation. |
| Payback period on project cost | - Around 1 year |

## CASE-2 INSTALLATION OF GILLED ECONOMISER ON 85 T/HR, 50 KG/CM$^2$ BOILER AT MADRAS REFINERY LIMITED.

The refinery has a battery of 3 identical, John Thompson boilers, each capable of generating 85 T/hr of steam at 50 Kg/cm$^2$ and 430$^o$C temp. All these boilers were originally installed without economiser/air preheater, as per haps at that time heat recovery from flue gases was not considered economically viable. Air preheater was subsequently installed on one boiler and space was found to be insufficient for same on other two boilers.

It was then realised that a gilled tube economiser would be more compact and hence could be retrofitted in the space available. The installat~~ion~~ would however be subject to certain special requirements like :

- Due to very high sulphur content (6.5%) in the fuel, precautions to prevent low temp. corrosion will be necessary.
- Due to reduction in quantity of fuel fired, steam temp. at the outlet of superheater could come down.
- Extra pressure drop on gas side may result in squeeze on ID Fan capacity.

These requirements were taken care of as follows:

- The economiser installed, comprises tubes of two configurations welded steel gill type for higher gas temp. section and cast Iron protected carbon steel type for sections prone to acid corrosion.
- An additional external superheater has been installed to raise the temp. of saturated steam before it goes to primary superheaters, to ensure against reduction in degree of super heat. This has been done for the first time in country for

power boilers.

- Proper pitch selection as well as 'in line' configuration of gills ensures against excessive pressure drop on gas side.

The design was overviewed by our collaborators, M/s. Senior Green of U.K. who have installed gilled economisers on boilers of upto 600 MW capacity. The order was received through global tenders, against competitions from world giants.

The project.cost for both the boilers was around Rs. 90 lacs while savings are anticipated to be of the order of Rs. 2.3 crores/yr.

## SPECIFICATIONS OF MRL ECONOMISERS:

### A. SUPERHEATER

Duty - 1009.8 x $10^3$ Kcal/hr

Steam flow - 85 T/hr

Rise in steam temp - 12,3°C.

Gas side pressure drop - 5.9 mm wc

Tube details - 64 Nos. welded steel gill type.

### B. ECONOMISER

Duty - 6418.5 x $10^3$ Kcal/hr

Feed water flow - 85 T/hr

Rise in F.W. Temp. - 73.7°C (From 105°C to 178.7°C)

Drop in flue gas temp. - 201.2°C (from 366.6°C to 165.4°C)

Gas side pressure drop - 45.5 mm wc

Tube details - 64 No. welded steel gill
304 No. C.I. protected carbon steel.

## CASE - 3

## INSTALLATION OF VAPOUR ABSORPTION CHILLERS BASED ON D.G. SET HEAT RECOVERY AT THOMSON PRESS.

M/s. Thomson Press are a most modern printing house, having centrally air conditioned facilities. Air conditioning at the moment is being achieved with 3 Nos. conventional, reciprocating chillers of 40 TR capacity each. Due to expansion of facilities, the total A/C load is expected to go up to around 250 RT in immediate future.

Power situation in the area in which the company is located is quite bad and the company has to operate its D.G. Sets for more that 20 hrs every day. The company has 2 D.G. sets of 1015 KVA each, installed for this purpose. It was clear to the Management that atleast in the near future, there would be no way out, but to operate D.G. Sets, which, anyway is costlier than grid power.

A proposal was therefore mooted regarding recovery of waste heat from D.G. Sets and using the same for operating the vapour absorption chillers. The overall energy cost could therefore, be brought down. In view of the contemplated expansion, the company wanted to have an installed capacity of around 400 RT, for which 1800 Kg of steam at a pressure of 8 $Kg/cm^2$ would be required, through use of double effect chillers. On the other hand, an estimation of steam generation potential from D.G. sets showed that upto 800 Kg of steam could be generated from both the sets. It was therefore decided that a oil fired package boiler be installed to meet the balance of steam requirements.

The final system installed comprised of following components:

- 2 waste heat recovery boilers, one on each D.G. Set.

- 2 oil fired package boilers, one to be operated on continuous basis, while the other to be a standby for periods when D.G. sets do not work.

- A two stage, 400 RT nominal capacity, steam fired vapour absorption chiller, imported from Japan.

- All associated piping, low side equipments, water softner and gas bypass valve.

The additional investment on this project, over and above the money the company would be spending had they gone in for conventional chillers, is around Rs. 30 lacs, which is expected to be recovered in 1½ years time, after taking into account financial benefits due to accelerated depreciation, etc. The project specs are enclosed.

However, apart from monetary savings, the company considers the main advantage of the project in reduction of dependence on grid supply, reduction in maintenance and operation skill requirements for chillers and a quiet operation.

**THERMAX**

# THOMSON PRESS - AIR CONDITIONING WITH VAPOUR ABSORPTION CHILLERS.

CAPACITY OF D.G. SETS - 2 Nos. PCTBCW MAKE, 1015 KVA each.

EXHAUST TEMP. - 450°C.

AVERAGE LOAD - 75%

MINIMUM LOAD - 500 KW

COST OF GRID POWER - 0.8 KWH

COST OF POWER FROM D.G. SET - Rs. 1.1 /Kwh

DESIGNED CAPACITY OF EXHAUST GAS BOILERS AT 75% LOAD - 400 KG/Hr each.

CAPACITY AT 500 KW - 300 KG/Hr each.

CHILLER CAPACITY - 400 TR

STEAM REQUIRED AT FULL LOAD - 1800 KG/HR

OIL FIRED BOILER CAPACITY - 1000 KG/HR each.

## CASE 4

## INSTALLATION OF CERAMIC RECUPERATOR ON BOX TYPE FORGING FURNACES.

The company is one of the largest forging companies in India. They have a number of large furnaces, all firing L.D.O. Temperatures, maintained are around 1200°C. The company has been on the look out for a reliable heat recovery system, for a long time, without much success. Due to high flue gas temperatures, metallic recuperators were not expected to be of great benefit. Ceramic Recuperators on the other hand, could handle these high temp. gases with ease and thus save substantial money for the company.

Two box type furnaces were therefore chosen in the initial phase for installation of Ceramic recuperators. Each of these consumes around 150 Kg/hr of L.D.O. 4 Nos. North American LAP burners have been installed on each furnace. Our experience has shown that this type of burners can handle preheated air upto around 500°C. Hence recuperators were designed for inlet flue gas temp. of around 1100°C and an outlet air temp. of around 460°C at 40% effectiveness. The eductors provided on the gas side, compensate the pressure drop across the recuperator. Separate blowers have been provided for eductor air in each of the furnaces. Separate blowers for atomising air already existed.

The post commissioning trials have shown a preheated air temperature of 450°C and pressure drops of 6 mm wc and 37.5 mm wc on gas and air sides respectively. No adverse effect has been observed on burner/furnace operation. Eash of these installations are likely to save 15-20 litres of oil per hour, resulting in a simple payback of less than 3 months.

THERMAX

## SPECIFICATIONS OF CERAMIC RECUPERATORS ON BOX TYPE FORGING FURNACES.

Type of Recuperators - single block, Ceramic matrix type.

Model No. - TCR-150

Type of burners - LAP

Make and model - Wesman, North American No. 5425-6

Number of burners on each furnace - 4

Pressure at burner - 20" of water column

Flue gas outlet temp. as measured - 1060°C

Designed effectiveness of recuperator - 40%

Designed press. drop gas side - 15 mm wc

Designed press. air side - 50 mm wc

Actual press. drop gas side - 6 mm wc

Actual press. drop air side - 37,5 mm wc

Oil consumption before installation of recuperator - 150 Kg/hr

Oil consumption after installation of recuperator - 130-135 Kg/hr

# INDUSTRIAL COGENERATION

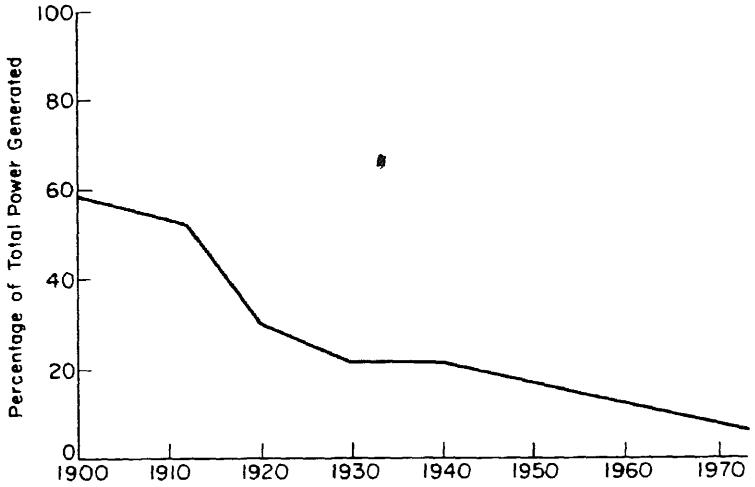
VIRENDRA S. KOTHARI
TATA ENERGY RESEARCH INSTITUTE
NEW DELHI

WORKSHOP ON ENERGY MANAGEMENT IN INDUSTRIAL SECTOR
NEW DELHI
NOVEMBER 24-26, 1986

# COGENERATION

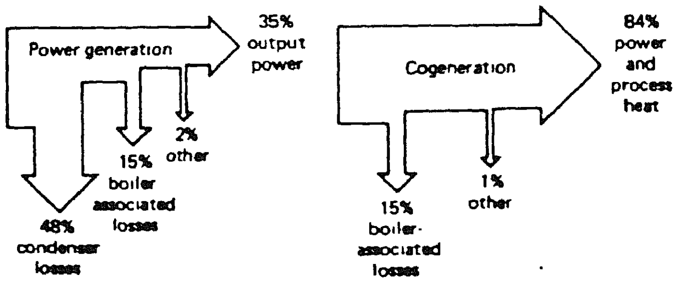
- Cogeneration is the combined production of electrical or mechanical energy and thermal energy

- Cogeneration is not a new concept

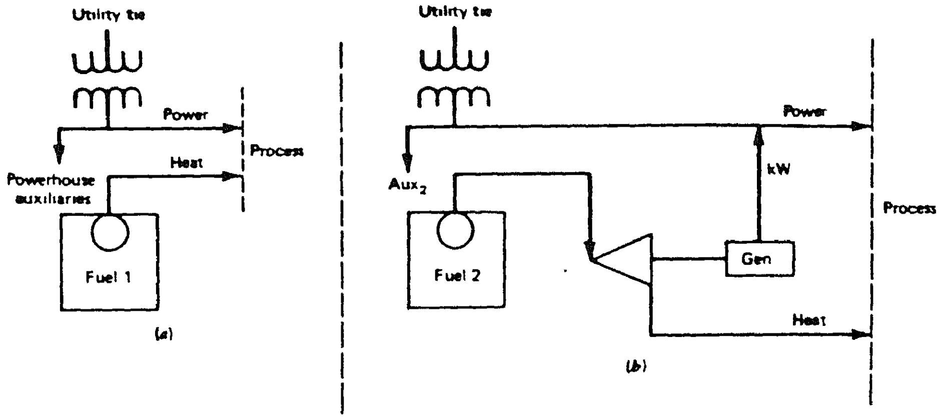


Since 1900, industrial on-site power generation in the United States has declined relative to total generation

- Cogneration vs. utility generation


Power generation
35% output power
2% other
15% boiler associated losses
48% condenser losses
Cogeneration
84% power and process heat
1% other
15% boiler-associated losses

- Performance of cogeneration system



$$\mathrm{FCP} = \frac{(\mathrm{fuel})_2 - (\mathrm{fuel})_1}{\mathrm{kW} - (\mathrm{PH\ aux})_2 + (\mathrm{PH\ aux})_1}$$

$$= \frac{\text{total fuel} - \text{process fuel credit}}{\mathrm{kW} - \Delta\ \mathrm{PH\ aux}}$$

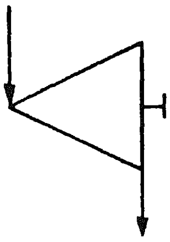
Fuel chargeable to power concept. (*a*) Noncogeneration system. (*b*) Cogeneration system

# COGENERATION TECHNOLOGIES

- Cogeneration technologies generally based on two power cycles
  - Topping Cycle : Fuel used to produce electric or mechanical power. Waste heat from power production then used to provide useful thermal energy
  - Bottoming Cycle : Fuel used to provide heat for process. Waste heat from process then used for power production
- Topping cycle has wider industrial applications
- Topping cycle systems
  - Steam turbine systems
  - Gas turbine systems
  - Combined gas-steam turbine systems
  - Diesel engine systems
- Bottoming cycle systems
  - Steam Rankine cycle systems
  - Organic Rankine cycle systems

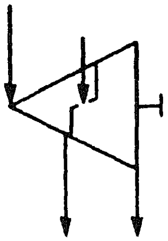
# STEAM TURBINE SYSTEMS

- Most common cogeneration system
- Steam turbine types
  - Backpressure
  - Extraction
  - Extraction condensing

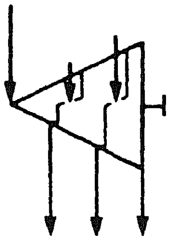


Straight
Noncondensing

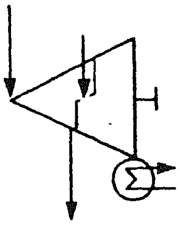
(SNC)



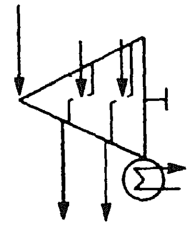
Single Automatic-
Extraction-
Noncondensing
(SAENC)



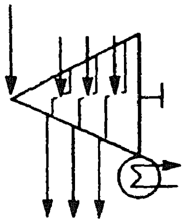
Double Automatic-
Extraction-
Noncondensing
(DAENC)



Single Automatic-
Extraction-
Condensing
(SAEC)

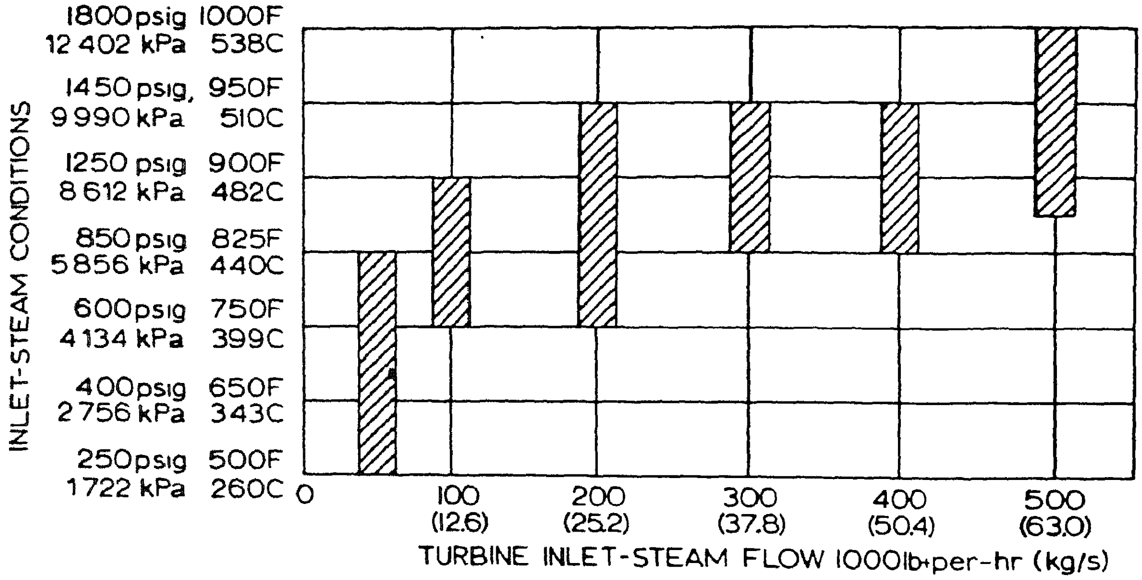


Double Automatic-
Extraction-
Condensing
(DAEC)



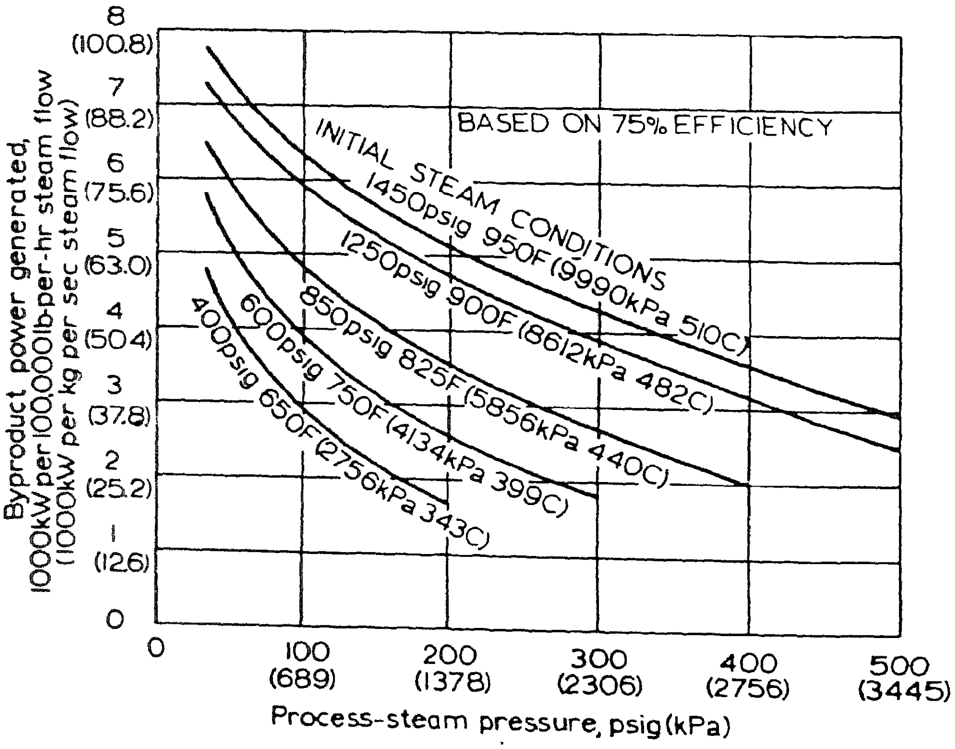
Triple Automatic-
Extraction-
Condensing
(TAEC)

- **Unit size : 0.5 - 100 MW**
- Electric efficiency
  - Full load : 14-28%
  - 50% load : 12-25%
- Heat rate
  - Total : 11,550-22,750 kJ/kWh
  - Net : 4,250- 5,700 kJ/kWh
- Electricity to Steam ratio : 28-70 kWh/GJ
- Availability : 90-95%



*Courtesy Power magazine*

Usual throttle steam conditions vs. steam flows[4]



*Courtesy Power magazine*

By-product power generation vs. initial steam conditions.[4]

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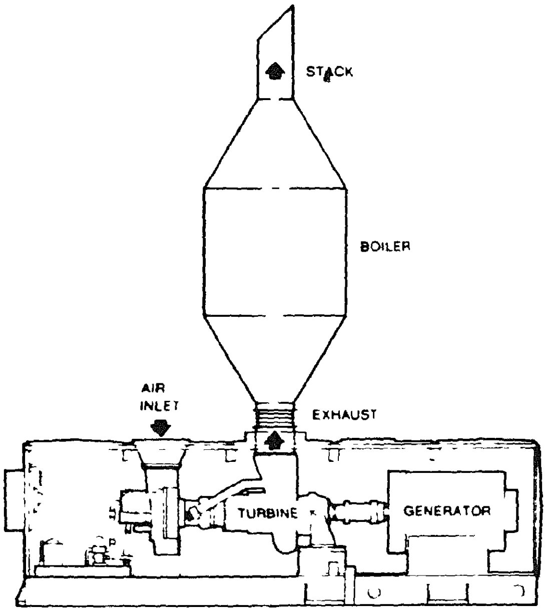
[4] W. B. Wilson, "How to Use Steam Turbines in Refining, Petrochemical and Chemical Industries." *Power*, February, 1960, p. 78.

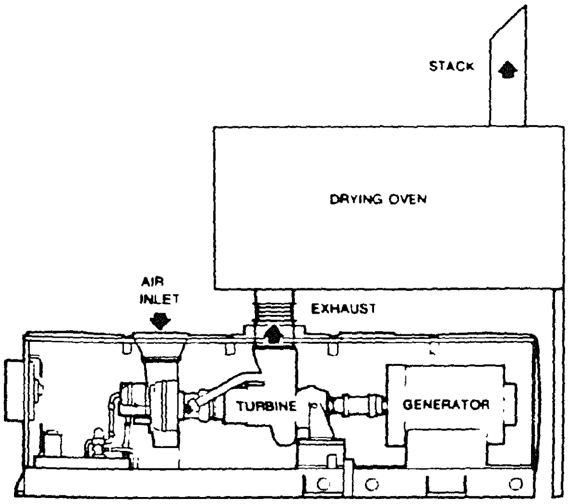
# GAS TURBINE SYSTEMS

- System consists of gas turbine and waste heat recovery system
- Waste heat in exhaust gases recovered for
  - Heating process fluids or generating steam in unfired or supplementary fired waste heat boiler
  - Direct process use
  - Use as preheated combustion air



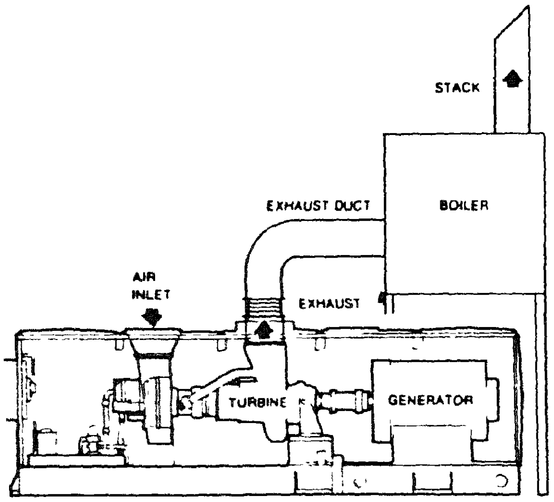
| | Saturn | Centaur | Mars |
|---|---|---|---|
| Stack Temperature °F | 269 | 270 | 282 |
| Steam Output lb/hr | 6848 | 18 886 | 43,825 |
| Exhaust Temperature °F | 835 | 818 | 877 |
| Fuel Input million Btu/hr | 12 8 | 38 5 | 95 4 |
| Electrical Output kW | 800 | 2795 | 8513 |
| Air Mass Flow thousand lb/hr | 49 3 | 140 1 | 299 0 |
| Net Fuel Rate Btu/kWh | 4979 | 5075 | 5790 |

Turbine Exhaust Used to Produce 15 psi Steam with No Additional Fuel Burned



| | Saturn | Centaur | Mars |
|---|---|---|---|
| Heat Credit millions Btu/hr | 9 55 | 26 55 | 63 32 |
| Exhaust Temperature °F | 835 | 818 | 877 |
| Fuel input million Btu/hr | 12 8 | 38 5 | 95 4 |
| Electrical Output kW | 800 | 2795 | 8513 |
| Air Mass Flow thousands lb/hr | 49 3 | 140 1 | 299 |
| Net Fuel Rate Btu/kWh | 4063 | 4276 | 3768 |

Turbine Exhaust Used Directly as Hot Air Source



| | Saturn | Centaur | Mars |
|---|---|---|---|
| Stack Temperature °F | 250 | 250 | 250 |
| Steam Output lb/hr | 16 947 | 48 150 | 101 633 |
| Additional Fuel to Burner million Btu/hr | 11 67 | 33 76 | 65 7 |
| Exhaust Temperature °F | 835 | 818 | 877 |
| Turbine Fuel Input million Btu/hr | 12 8 | 38 5 | 95 4 |
| Electrical Output kW | 800 | 2795 | 8513 |
| Air Mass Flow thousand lb/hr | 49 2 | 140 1 | 299 |
| Net Fuel Rate Btu/kW | 3313 | 3673 | 3768 |

Turbine Exhaust with Duct Burner to Supplemental Fire Exhaust Temperature to 1700°F in 200 psig Boiler

- o Unit size : 0.1-120MW
- o Electric efficiency
  - - Full load : 24-35%
  - - 50% load : 19-29%
- o Heat rate
  - - Total : 9,250-13,450 kJ/kWh
  - - Net : 5,200- 6,150 kJ/kWh
- o Electricity to Steam ratio : 130-215 kWh/GJ
- o Availability : 90-95%

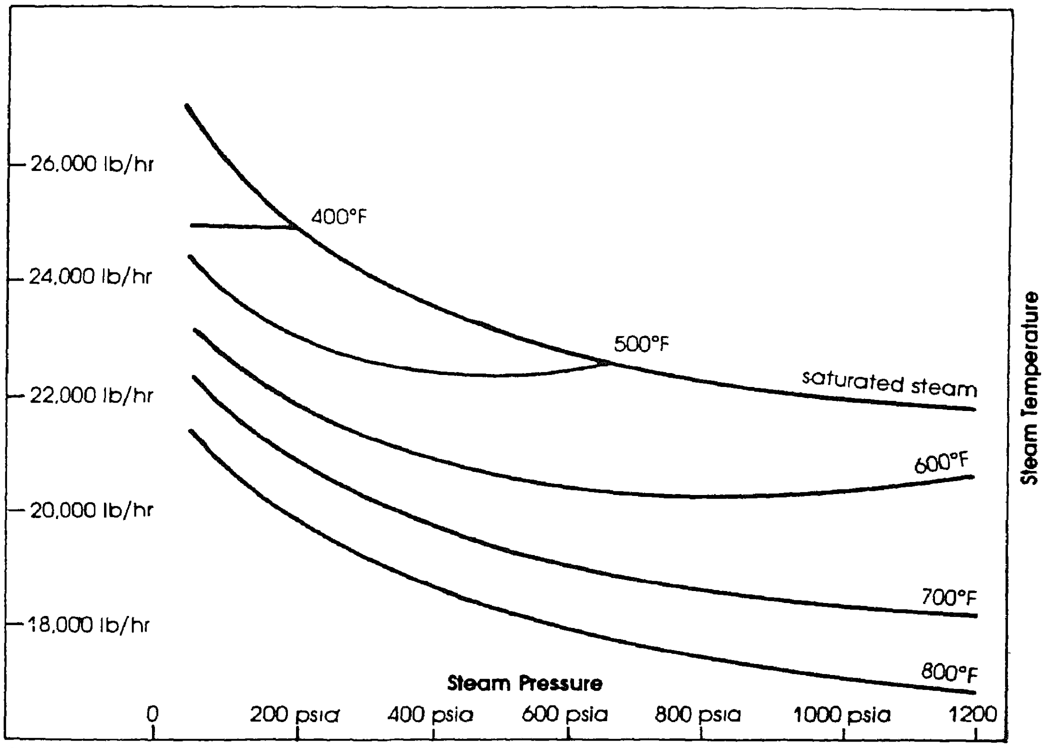
# Ruston TB5000 Gas Turbine Cogeneration Performance

### Gas Turbine Output

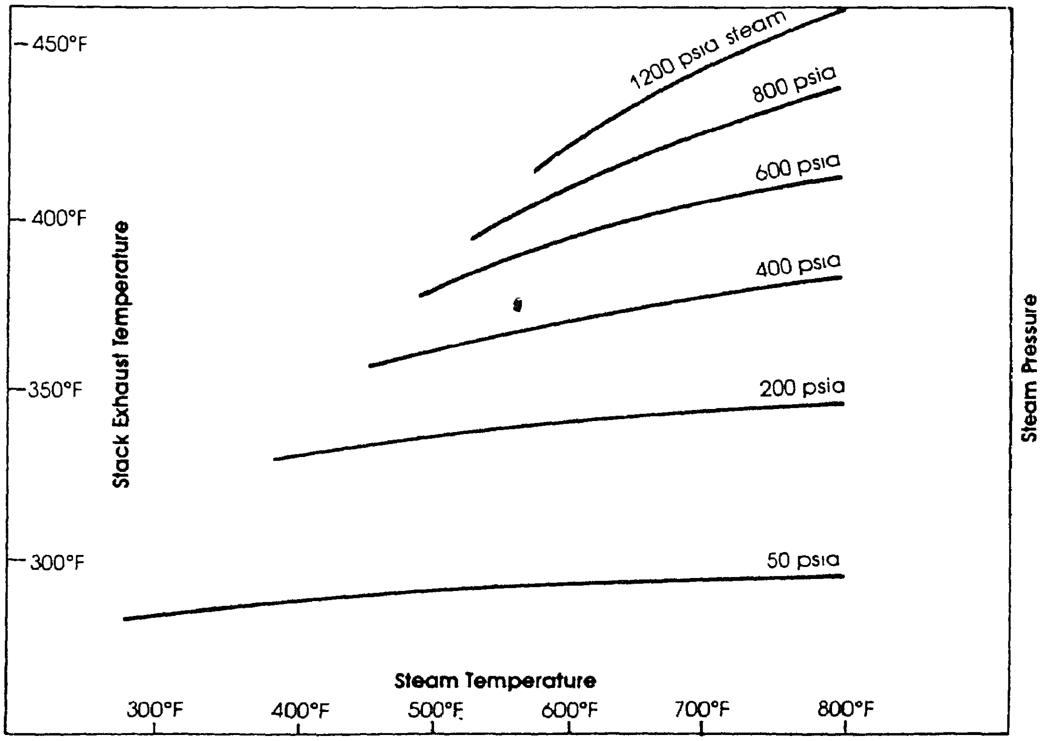
| | |
|---|---|
| Power | 3460kW' |
| Heat rate | 14,130Btu/kWh |
| Fuel flow | 2574lb/hr |
| Air flow | 45 9lb/sec |
| Exhaust gas | 918°F |
| Specific power | 75 4kW-sec/lb air |

### Operating Conditions

Computer-derived steam curves are calculated for base load output of the gas turbine at 59°F sea level site conditions burning natural gas fuel, with 4-inch water inlet and 10-inch outlet losses, with the exhaust ducted into an unfired single-pressure level waste heat recovery boiler



Steam Production Capability



HRSG Heat Rejection

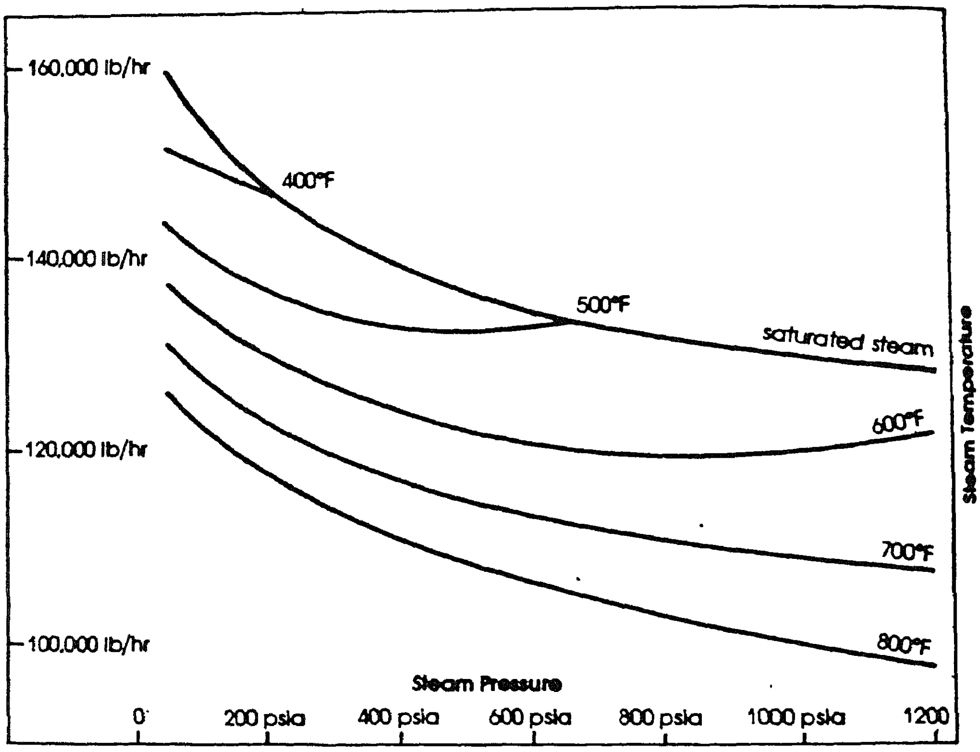
# General Electric PG5361 Gas Turbine Cogeneration Performance

## Gas Turbine Output

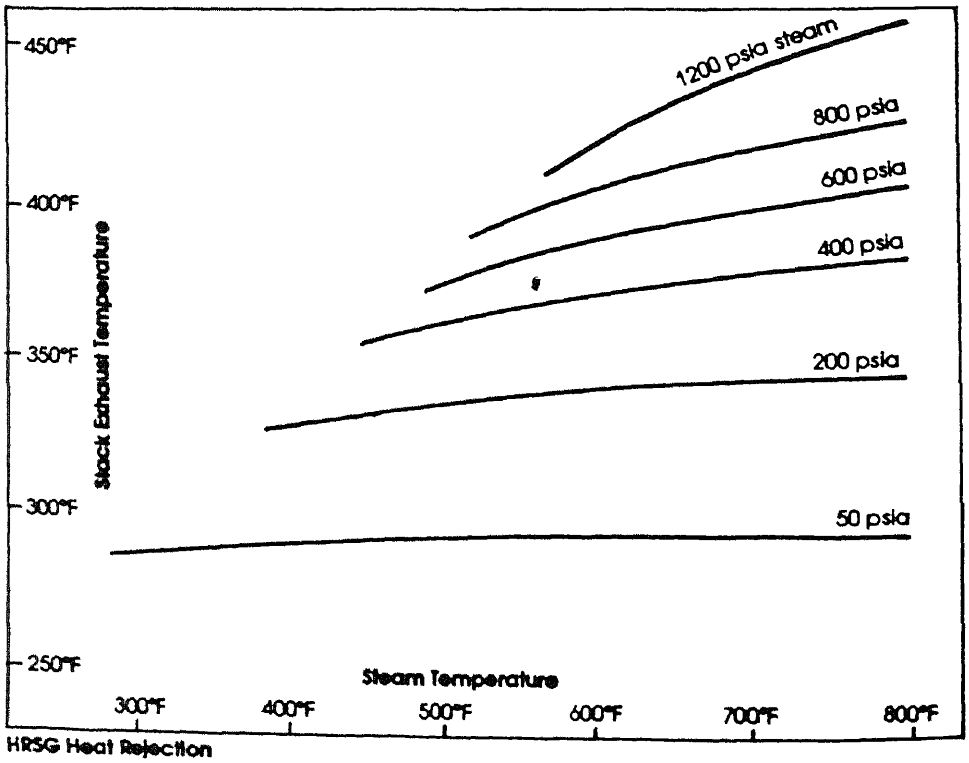
| | |
|---|---|
| Power | 25,010 kW |
| Heat rate | 12,430 Btu/kWh |
| Fuel flow | 16,362 lb/hr |
| Air flow | 267 lb/sec |
| Exhaust gas | 922°F |
| Specific power | 93.7kW-sec/lb air |

## Operating Conditions

Computer-derived steam curves are calculated for base load output of the gas turbine at 59°F sea level site conditions burning natural gas fuel, with 4-inch water inlet and 10-inch outlet losses, with the exhaust ducted into an unfired single-pressure level waste heat recovery boiler.

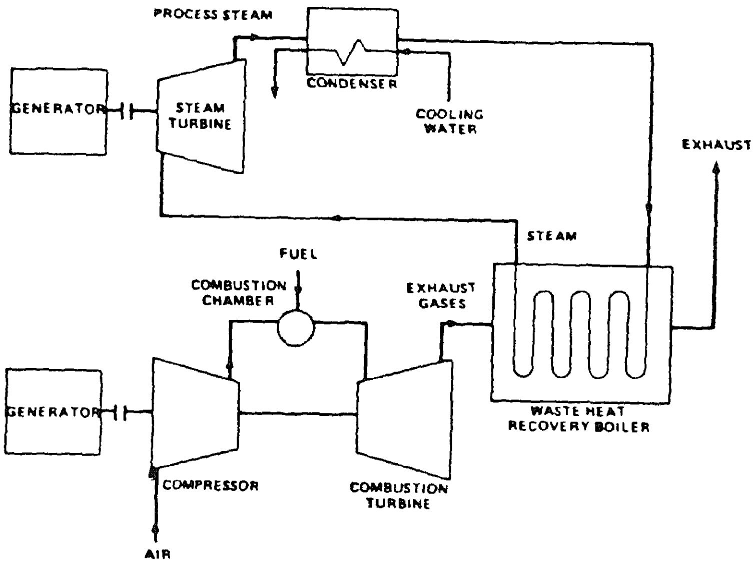


Steam Production Capability

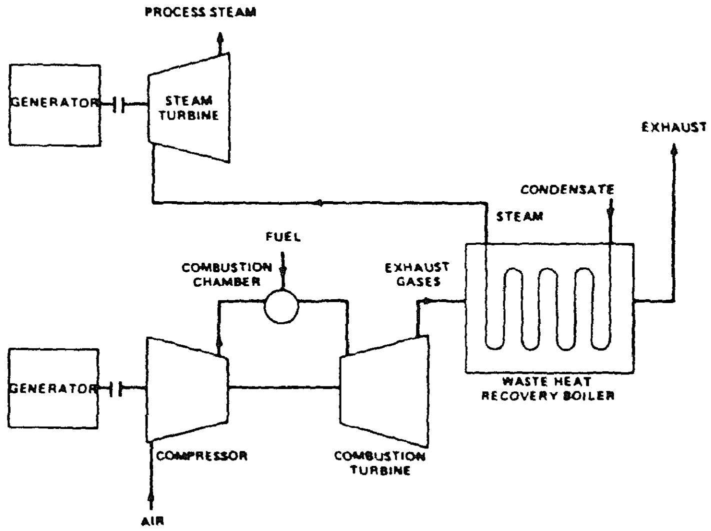


HRSG Heat Rejection

# COMBINED CYCLE SYSTEMS



Combined cycle for power generation.



Combined cycle for power and process heat generation.

- Unit size : 4-120 MW
- Electric efficiency
  - Full load : 34-40%
  - 50% load : 25-30%
- Heat rate
  - Total : 7,600-9,500 kJ/kWh
  - Net : 4,750-5,700 kJ/kWh
- Electricity to Steam ratio : 165-300 kWh/GJ
- Availability : 80-85%

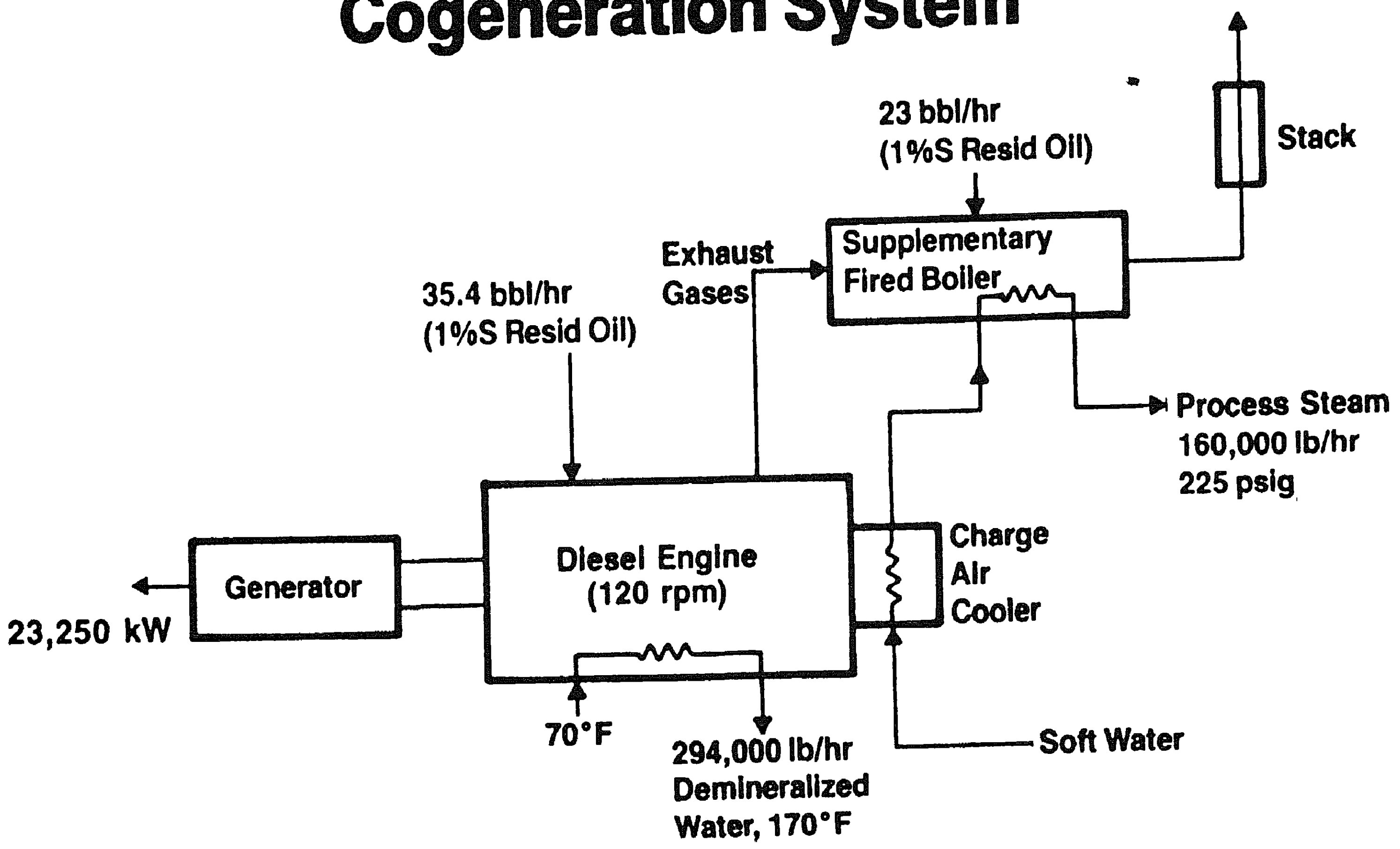
# DIESEL ENGINE SYSTEMS

- Diesel engine types

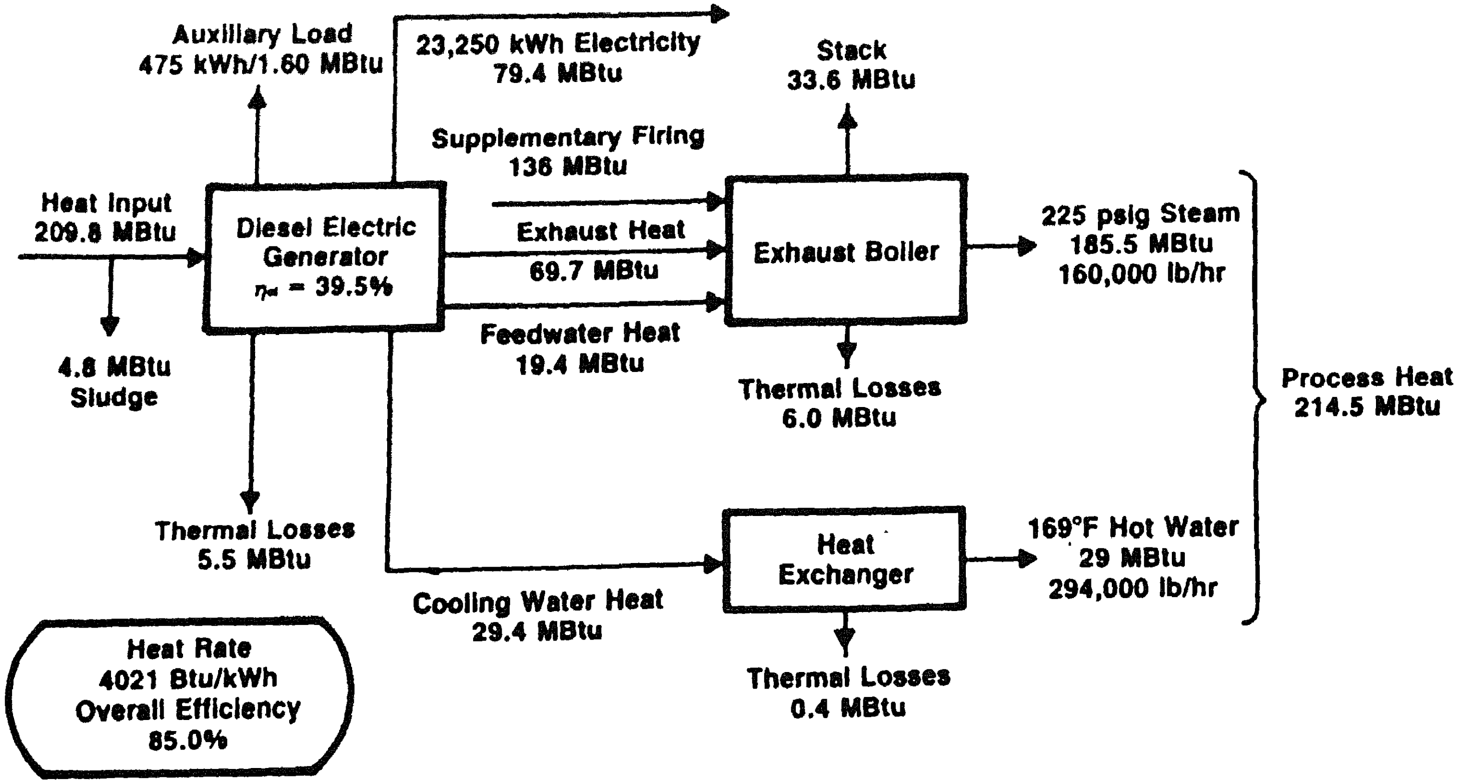
| Type | Speed (rpm) | Power (MW) | Cycle | Efficiency (%) |
|---|---|---|---|---|
| High speed | > 900 | 0.1-1 | 4 stroke | 34 |
| Medium speed | 400-900 | 1-10 | 2/4 stroke | 38 |
| Low speed | < 200 | 5-30 | 2 stroke | 40 |

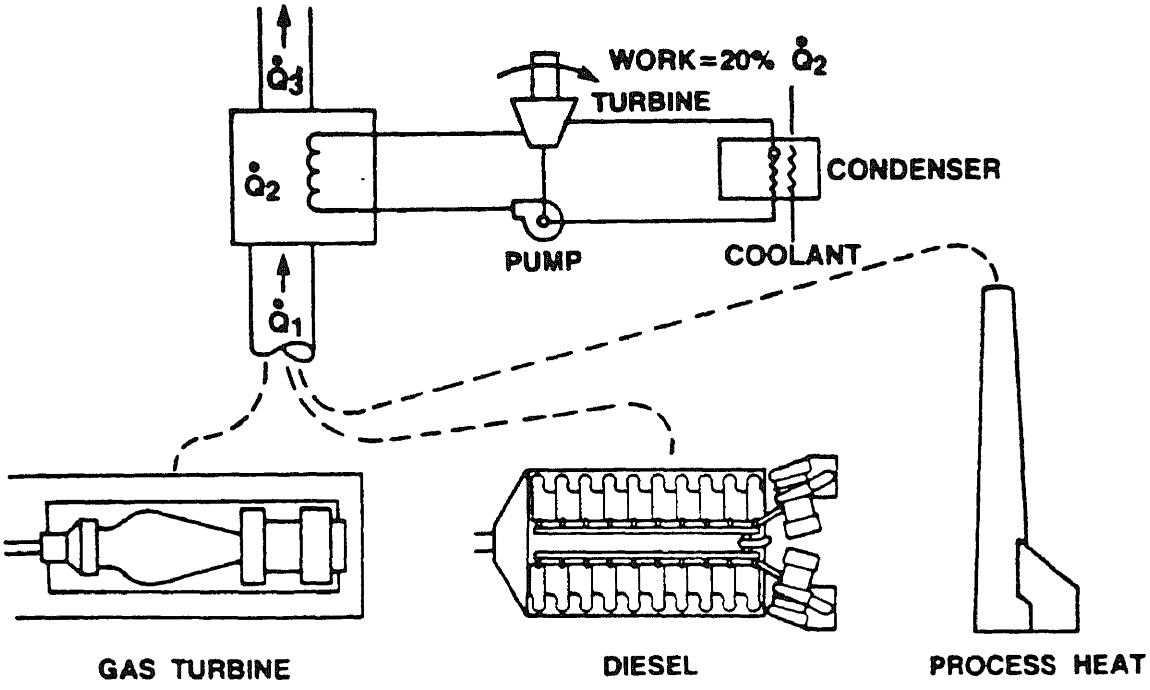
- Unit size : 0.1 - 30 MW
- Electric efficiency
  - Full load : 33-40%
  - 50% load ; 32-39%
- Heat rate
  - Total : 7,850-9,750 KJ/kWh
  - Net : 5,700-7,100 KJ/kWh
- Electricity to steam ratio : 330-660 kWh/GJ
- Availability : 80-90%

# Hoffmann–La Roche Diesel Cogeneration System

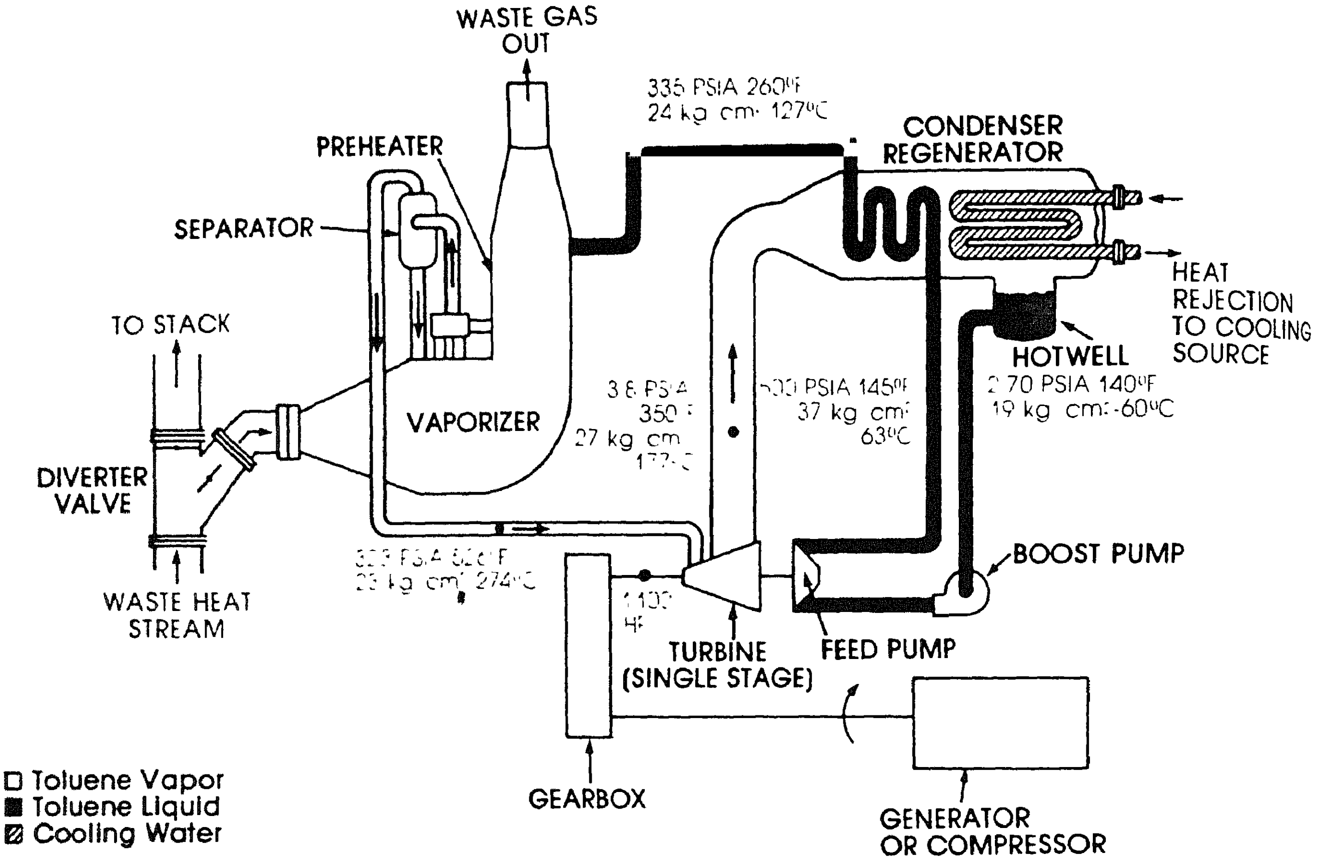


# Energy Flow Diagram
# For
# Diesel Cogeneration System

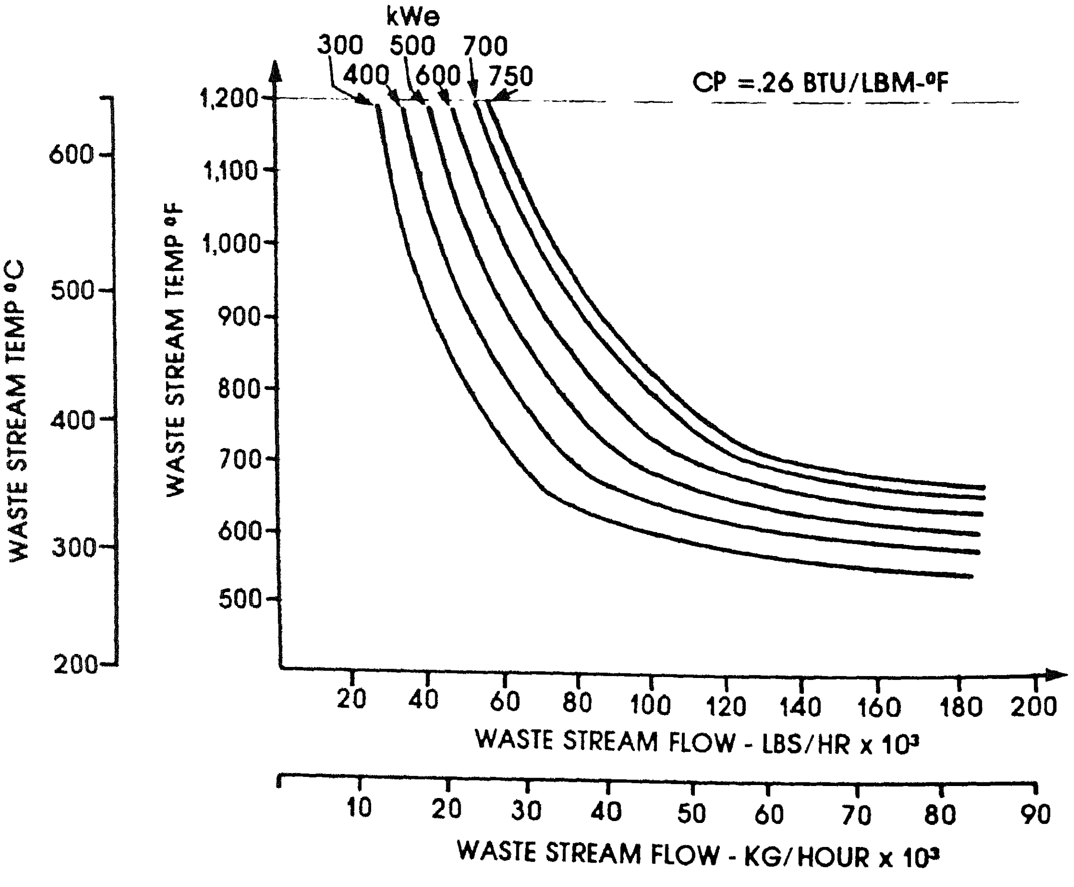




Bottoming Cycle Concept

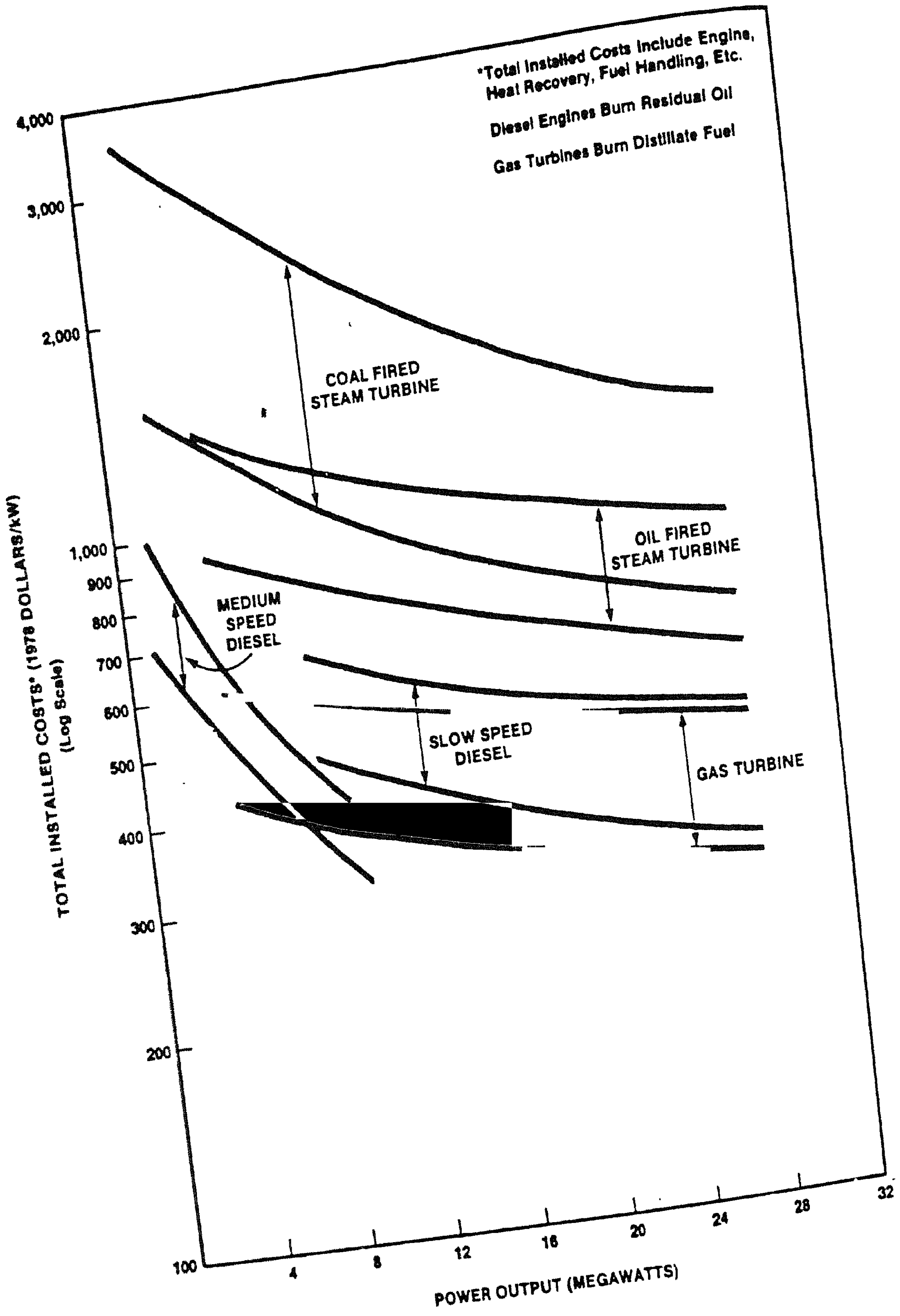


ORC CAPACITY

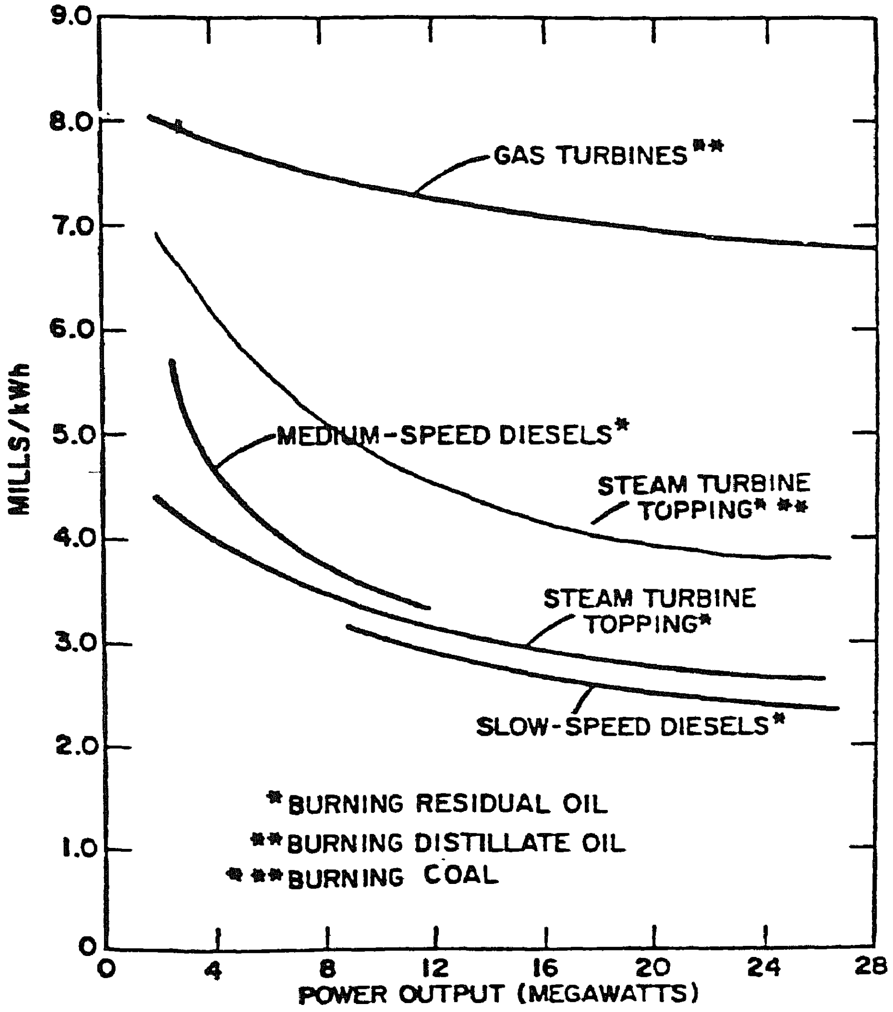


# FUTURE TECHNOLOGIES

- Fluidised bed boiler - Steam turbine system
- Pressurised fluidised bed boiler - Gas turbine system
- Coal gasification combined cycle system
- Fuel cells
- Stirling engine systems



Cogeneration Systems Total Installed Costs*

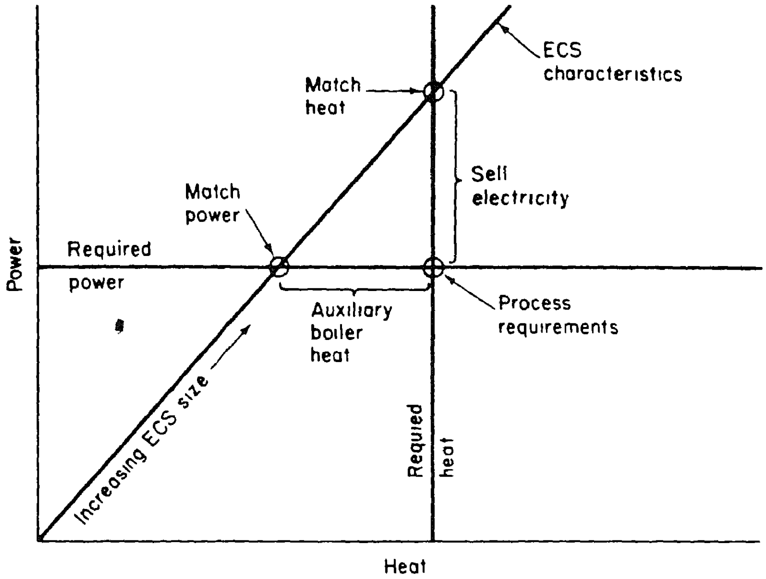


Cogeneration Systems Operation and Maintenance Costs

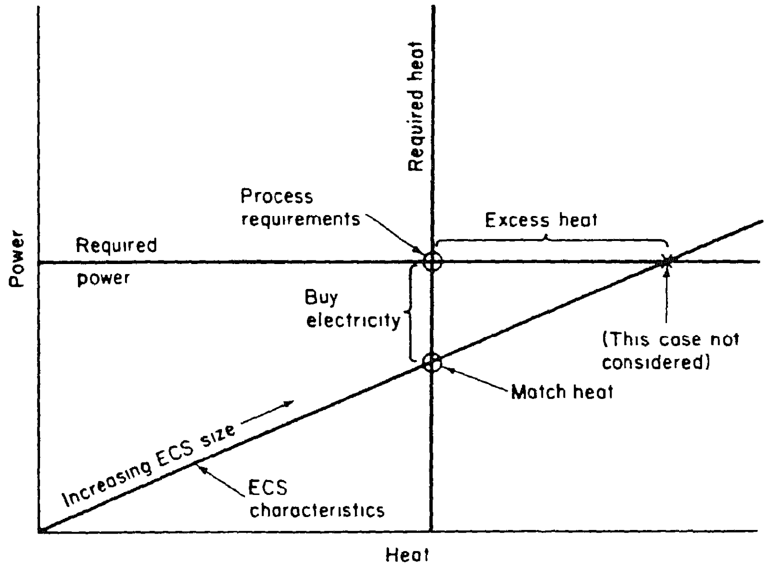
# COGENERATION SYSTEM SELECTION AND DESIGN

- Technical factors
  - Electricity requirement
  - Thermal energy requirement : temperature level, quantity
  - Daily, monthly, seasonal variation in electricity and thermal energy demands
  - Balance between electric and thermal demand
  - Fuels availability
  - Retrofit vs. new installation
  - System reliability
  - Operation and maintenance aspects

- Economic factors
  - Available capital
  - Rate of return required
  - Energy costs
  - Buy-back rates



Match between process and energy-conversion system (ECS) when power-heat ratio of ECS is greater than required



Match between process and ECS when power-heat ratio of ECS is less than required

# INSTITUTIONAL AND REGULATORY ASPECTS

- Legislation enacted in a number of countries, e.g., U.S.A., U.K., France etc. to encourage cogeneration
- In the U.S., PURPA (Public Utility Regulatory Policy Act, 1978) requires utilities must buy power offered by cogenerator at its avoided cost at a negotiated rate
- Major issues pertain to both utility and cogenerator concerns
  - Conditions for purchase of cogenerated power by utility
  - Purchase rates
    - Avoided cost concept
    - Time (peak, off-peak) or seasonal component
  - Interconnection
  - Wheeling
  - Banking
  - Effect of dispersed cogenerators on grid
  - Effect of grid perturbations on cogeneration system

### Co-Generation Potential

| Industry | No. of Units Surveyed | Total power demand MW | Co-generation potential* MW |
|---|---|---|---|
| Pulp & Paper | 3 | 37.5 | 56.0 |
| Refineries | 4 | 37.3 | 40.0 |
| Rayon | 3 | 17.1 | 28.0 |
| Chemicals | 9 | 33.0 | 47.0 |
| Fertilisers | 9 | 193.0 | 250.0 |

* The co-generation potential has been determined, on a site by site basis, with regard to suitably tailored power-steam cycles.

### Co-Generation Investments

| Type of Unit | Captive generation possible (MW) | Incremental Investment (Rs. lakhs) | Incremental Investment (Rs./KW) |
|---|---|---|---|
| Pulp & Power (200 tonnes/day) | 28 | 576 | 2057 |
| Rayon (4000 tonnes/annum) | 14 | 342 | 2630 |
| Chemicals (Polymer —30,000 tonnes/ annum) | 17.5 | 384 | 2194 |
| Fertiliser (Urea— 350,000 tonnes/ annum) | 18 | 400 | 2222 |

# Background Material On Energy Models - Objectives , Techniques and Applications

By
Leena Srivastava

Prepared for presentation at the Vigyan Bhawan, New Delhi for the "Workshop on Energy Management in Industrial Sector", November 24-28, 1986.

## What are models

Models are a set of mathematical equations representing the behaviour of any system that has been modeled and modelling is the use of these general mathematical and statistical techniques in either an economic engineering or systems approach.

## What modelling can contribute

Modelling allows us to make systematic use of fragmented pieces of knowledge and expert opinions. One way of looking at modelling is that it permits us to carry out rigorously a weighting scheme that may involve estimating and applying differential weights to hundreds of factors -- be they assumptions or pieces of scientifically derived data. In the case of energy modeling, we deal with science, technology, and human behaviour. In oil refining, for example, we know the physical properties of crude oil and of refined petroleum products. How much of each product is actually to be produced is a decision made by managers and is the result of their analysis of the market, availability of future supply, near-term demand, interest rates, and many other factors.

Through modeling, we can enforce consistent and explicit accounting of energy resources as they move through the production, transportation, transformation, inventory, and consumption phases of their life cycle. Multicriteria analysis allows us to analyze futureoriented scenarios under different assumptions and competing objectives. Since modeling can be viewed as putting together current knowledge of the real world and the best assumptions and conjectures from experts, the rigors of modeling can identify and help analyze apparently counter-intuitive relationships. Without a model, these would be more difficult or impossible to uncover.

Another contribution of modeling is that it allows simultaneous examinations of various interrelated parts of the energy and economy systems. While energy modeling in itself is a valuable input to government and business decisionmakers, carrying out such modeling without explicit consideration of the overall economic environment leads almost surely to incomplete and potentially misleading results.

While acknowledging the potential value of modeling to the consideration of energy issues, we may not really be able to measure the specific contributions of energy modeling. What tests of success should we use? Consider an example from the private business sector. A simulation model of an oil refining process may be used to manage the production slate of an oil refinery. If the model does not correctly calculate outputs of various products, then it can be fine-tuned until it meets design specifications. On the other hand, in a public agency responsbible for energy information, the goal is to support decision-makers dealing with less well-defined problems. Models can assist a policymaker by:

- helping him think through a set of options systematically;
- identifying critical points or decision points for possible policy action;
- identifying robust aspects of policies or energy/economy systems with respect to key uncertainties; and
- providing fairly specific projected outcomes that would result from alternative decisions.

Prior to trying to assess the value of a model to a policymaker, we should have answers to questions such as the following:

- What are the costs of not having projections or a comparative analysis of more than one option?
- How much of a policy decision was based on the output of a model? How much did each of several models contribute?
- Did the models help the policy-makers to organize their thoughts--to clarify or focus any decisions?

Without answers to these questions, we are simply left with: "Is the policymaker better off with the model solution or not?" Another way to think of that is, "What are the costs of not knowing?"

While energy models may allow us to make systematic, differentially weighted use of knowledge and assumptions, the extent of which they do this thoroughly and well is the key to giving the policymaker the benefits of assimiltation of a mass of input and reduction of complexity.

## Policy Models And Engineering Models

The models being used in the energy field can be divided into two kinds, policy models and engineering models. The latter are concerned with design of systems, with technical questions about how to construct things, with physical inter-relationships, etc. The former are concerned with decision making, with the social, economic, and environmental interfaces of the energy problem, with strategies and policies for meeting desired energy goals, and so on. It is fairly easy to assess the value of an engineering model. Policy models are not so easy to assess. For, these models are usually used to make policies with a relatively long time horizon. Also, it is hard to assess the relative role played by a model in a policy decision. The final decision is based on many inputs, not just that from the model, and even where the decision is heavily influenced by a model, the final implementation might be somewhat different than that recommended by the model.

The model builder needs to define the policy question in order to decide what kind of detail to build into the model to make it useful. The policy maker must know what kind of policy question he has to answer in order to determine what type of model would be suitable for answering it. As there is no model appropriate for all purposes. Therefore an articulation of the policy question to be answered is mandatory. Accordingly, a model can be evaluated only in terms of its usefulness for responding to a particular type of policy question. Also relevant for this evaluation is the time frame in which the policy question applies - some models are clearly appropriate for short-run analysis and others are applicable only in the long-run.

## Criteria For Model Choice

Once the policy question and a time frame have been established, the criteria for choosing a model come into play. From both the user's and the model builder's point of view, the following considerations should be taken into account:

1) a theoretical structure that incorporates functional demand, that is, demand for a particular service, and not for a particular tupe of energy

2) the effect of price
3) the effect of technological change
4) fuel substitution possibilities
5) a scheme for data disaggregation that can conveniently be aggregated to summarize results
6) the constraints of the natural resource base
7) the treatment of environmental effects
8) accuracy
9) level of aggregation
10) time horizon
11) cost.

For regression models a more specific list of characteristics are:

1) disaggregation by sector, region, and fuel type
2) the inclusion of price effects
3) attention to the theoretical structure of demand
4) a distinction between the capital stock of energy using equipment and the energy usage pattern.

## Conditions for Effective Model Utilization in Policy Decision-Making

### 1. Technical Quality

The models and analysis should be technically sound.

2. Focus

The models and the analysis should quantify answers to specific policy questions, and estimate the impact of alternative ways of answering those questions.

3. Timing

The timing of the analytical or modeling effort should be right.

4. Credibility of Output

5. Communication of Results

Either the decision-maker is trained in the skills of quantitative analysis and modeling or, more commonly, someone like a "translator" is involved.

## Techniques for Energy Modelling

The three most commonly used approaches to Energy Modelling in the current day are econometric modelling, process modelling and systems dynamics modelling. Econometric modelling has its underpinnings in economic theory. A regression equation is not necessarily an econometric model. Equation estimates such as Energy-GDP elasticities are basically correlation analyses of one variable with another. A well-known example of econometrically based energy economy model is the Hudson and Jorgenson Model (1974) in which the factor and production market models are in an input-output framework but are econometrically estimated.

The engineering or process group of models have their distinguishing features is their planning and their management nature. Programming models in particular provide optimum allocation rule for a particular objective function and set of inequality constraints.

Systems dynamics has emerged as an offspring of the development of computer systems and software. This has provided an extremely flexible tool for modelling complex phenomena from a number of different dimensions (time, space, etc.), enabling hierarchical levels of entry into the model by the model user, the linking of many sub-models.

Some distinguishing aspects of the above approaches are described in the following summary remarks:

a. Econometric modelling is primarily deductive in nature; it is also behavioural in that underlying optimization behaviour is assumed for producers and consumers. Alternative economic models may be descriptive, analytical, or predictive. Most analysis is conducted at relatively aggregated levels using estimates of "summary" statistics (or analytical measures) such as demand elasticities, elasticities of substitution, and multiplier estimates. An important feature of econometric modelling is its linkage to economic general equilibrium theory and economic welfare theory which provides the basis for economics (and econometric modelling) as a policy science.

b. Engineering, programming, and other systems of modelling tools are primarily empirical and descriptive in nature. Many programming techniques are used within economic analysis and an overlapping sub-discipline of "engineering economics" uses these techniques in performing cost accounting and cost-benefit analysis of engineering projects. This is a type of analysis distinct from economic modelling since cost analysis is only one aspect of economic analysis. The latter, in principle, would include market and general equilibrium effects, for example, on labour and capital markets (this also applies to pay-back and profitability analysis).

c. Systems dynamics modelling is relatively inductive and sometimes attempts to be "behaviourly realistic" (i.e. depicting actual real world activity in modelling a particular energy-economic system). Simulation analysis, rather than forecasting, is the primary use of these models. The systems dynamics approach is extremely flexible in terms of dealing with complex phenomena and can use a number of modelling methods within any single over-all systems (e.g. programming for one sub-model, etc.). One inherent limitation of behaviourly realistic system dynamic models occurs in explaining the reasons for a specific simulation result: the reasons within the model for a particular outcome may be as complicated and unclear as they are in the real world.

## Causal forecasting/econometric models

Once estimates of the parameters of an economic model are available, the model can be employed to forecast the dependent variable if the associated values of the independent variables are given. It is this forecasting method, relying on the causal interpretation of the economic model in question, that is usually meant by the terminology 'econometric forecast'. The model used can range in sophistication from a single equation with one or two explanatory variables to a large simultaneous-equation model with scores of variables.

While application of the econometric approach can give a general indication of how energy demand will evolve in response to fuel prices, it should be noted that this response cannot be stated in terms of specific technological changes, even though it is recognized that for a change in energy demand to occur, some change or modification to production technology must take place. Indeed, proponents of the econometric approach would argue that this is one of the advantages of the approach, in that the effect of technologies yet to be developed can be taken into account (without actually defining them). Of course, for this to be valid, one must suppose that the type of technological response induced by the price changes in the historical period that is subject to the econometric estimation will continue into the future.

## Process Models

An alternative to the econometric approach is that of socalled process model, in which the slate of technological alternatives is explicity stated, and for which the model then selects the optimum capital expansion path for that industry under some given fuel price trajectory. Obviously, technologies that have yet to be discovered cannot be captured by the model, which is not too serious for short planning horizons, given the very long gestation periods between discovery of a process, and its ultimate commercialization.

A process model can be viewed as a tool to derive energy demand curves for specific industries. That is, for some given level of production, (say P tons of finished steel per year), and for a given set of energy and non-energy prices, what quantity of energy will be demanded to sustain that level of output. Clearly that will depend on the specific technologies used in the production process, and in particular on the degree to which capital can substitute for energy.

Consider, as an illustrative example, a very simple model of the steel industry (Figure 7.2). Assume that there are J steelmaking processes (open hearth, electric arc, etc.), and let the amount of steel produced by each technology be denoted $x_j$. Then if the total production level for domestic steel is x, we require first that

$$\sum x_j \geq x$$

Next, let the existing capacity of each type be $C_j$. Then it follows that production each process cannot exceed the capacity of existing plus new mills of that type, i.e.

$$x_j \leq C_j + \bar{C}_j(N)$$

where $\bar{C}_j(N)$ is the capacity to be added over the planning horizon. In constraint form, in which all endogenous variables appear on the left hand side, (7.2) is written

$$x_j - \bar{C}_j(N) \leq C_j$$

Suppose there are K energy inputs (different fuels) and L non-energy inputs (labor, iron ore, etc.) and suppose that

ejk represents the unit requirement of energy of type k for process j

k cost per unit of k

fjl represents the unit requirement for the non-energy factor of production l for process j.

l cost per unit of l

then the total industry wide consumption of fuel k is given by

$$\sum_{j} xj \;.\; ejk = Ek$$

and the industry wide input of factor l is given by

$$\sum_{j} xj \;.\; fjl = Fl$$

Hence the cost to be minimized is

$$C = \lambda k . E_k + \pi l . F_l + C_j (N) . W_j . CRF(i,n)$$

where

$W_j$ is the capital cost for additions of type j.

CRF(i,n) is the capital recovery factor at discount rate i and planning horizon n.

It should be noted that each technological modification of some basis process (such as oxygen landing in open hearth steelmaking) would be represented in the model by a separate $x_j$, since sometimes even minor process and conservation modifications will result in drastic changes in the mix of factor (and thus also energy) inputs.

This simple Linear program, then, enables one to predict the future energy consumption in the iron and steel industry as a function of energy and non-energy factor prices, and as a function of the capital costs for different technologies. This is, to be sure, a highly simplified description of the industry. The objective function can be more complex, too, reflecting industry decision criteria that take into account such items as taxes and depreciation allowances, and may be framed in terms of a minimization of net present value rather than minimization of an equivalent annual cost. A dynamic version may also be necessary to be more precise in estimating the capacity expansion path of the industry.

Simulation models differ quits fundamentally to optimization models. An optimization model can be represented by

$$\text{Max (or Min) } f(x);$$
$$\text{subject to } g(x) = 0$$

that is, some function of x is optimized subject to a set of constraints on x; if the objective function and the constraint set are linear equations in x, and $x > 0$, we then have socalled linear programming model, many applications of which we have already discussed. In contrast, a simulation model can be represented simply by

$$h(x) = 0.$$

As an example, consider the following set of equations that link price, investment and consumption of some energy form:

$$Q = \alpha\lambda^{\beta} \tag{10.1}$$

$$I = Y(Q - Q_0) \tag{10.2}$$

$$\lambda = \sigma\frac{I}{Q} + \pi \tag{10.3}$$

where

= price

Q = consumption (demand)

I = investment

and where , , Y, , $Q_0$, , and are constants.

We thus have three simultaneous equations in three unknowns: because they are non-linear (for example, equation (10.3) involves a term that includes both I and Q), this cannot be solved by a standard elimination procedure (as one could in the case of a set of linear simultaneous equations). However, there are a number of iterative methods that can be used.

A major advantage of such simulation models is that we are not limited to linear functions: thus price-investment relationships can be captured with a greater degree of realism -- recall, for example, the difficulties of treating scale economies and fixed charges in the linear programming formulation. Indeed, in the simulation framework the functional relationships can be quite arbitrary -- although convergence properties may not be quite as well behaved as in the above hypothetical example. The major disadvantage of a simulation model, however, is that single run of the model rarely provides much in the way of policy guidance: alternative policies must each be simulated in turn, and the optimal policy evaluated on the basis of comparison of each run. Obviously, such a procedure only guarantees a *local* optimum: that is, we can identify the best choice from among the *finite* number of policy simulation runs. This contrasts with, say, the linear programming model, whose solution can be shown to be the *global* optimum (i.e., the optimum from among the almost infinite number of feasible solutions) -- always assuming we meet all of the necessary conditions of linearity and convexity.

## The Perils of Policy Modeling

Modeling for policy use is always difficult, and energy/economy modeling is especially difficult. First we must acknowledge that each time we choose a particular formulation concerning the functioning of markets, the general structure of a national economy, or a relationship between the energy component and the economy as a whole, we expose our modeling efforts to the problems and pitfalls of the underlying theory behind the structure we adopt.

The most obvious limitations of energy models or for that matter any model is their incompleteness . Any representation of reality cannot be true in every detail: at best one abstracts from reality those elements that are important and supresses unessential details. Particularly interesting from this point of view is the trade-off between time and energy. This trade-off between energy and time is so fundamental that it often goes unnoticed in discussions of energy policy.

The other important limitations of models is concerned with uncertainty. There are two sources of uncertainty - in parameters and intrinsic indeterminacy, because of the methamatical structure of the system, because of the underlying intractability of the world that is to be modeled. Most models depend on parameters often derived from historical time series. The question that arises here is on the accuracy of any forecasts/analysis based on these parameters (for ex. price elasticities) which are based on historical time series data ranging probablly over a wide span.

## Conclusions :

Energy problems are so large and so complex that existing technical tools and capabilities are overwhelmed by them. New and more powerful mathematical or computational tools must be developed and obviously one way to improve the performance of modeling is to make such new tools widely available to model builders.

It should be emphasized, however, that the development of new technical tools will not be enough to bridge the gap between the complexity of energy problems and the lack of power of existing tools. Energy problems are sufficiently complex that it is likely that any policy model used to study them will be required to make rather strong simplifying assumptions in order to be mathematically and computationally tractable. What is required, then, is a new attitude about the role of models, which is different from the traditional engineering attitude. Models in policy analysis have a different role to play, as one of a number of devices to gain intuition and understanding about complicated systems, when it is hopeless to gain the same level of understanding as one can about a machine or a plant. One of the reasons that many decision makers are disappointed in the assistance provided by models is that they are used to the very definitive, "right or wrong" kinds of answers attainable from engineering models, and expect too much of policy models. Hence, one of the methods for improving the performance of models is not so much improving their performance per se, but changing expectations about this performance. In sum, models used to make policy should be thought of as learning and communication devices, used to identify and assess alternatives, make precise otherwise hard to specify ideas, and used to assist in thinking carefully about complicated interconnections, relationships, etc. If one emphasizes the learning aspects of modeling, and de-emphasizes the role of the model as the final source of a decision, a big step has been taken in putting models in their proper place.

Now if one accepts the idea that a model is a learning device, it follows that the user must participate in the modeling exercise as much as possible so as to benefit from the educational experience. There is one other point that goes along with this last one. A decision maker should not ask a model to provide a single number for an answer. Nor should the decision maker make too much of any numbers which are produced. He should be more concerned with the pattern or general direction of effect predicted.

# 1

# Storage, handling and preparation of fuel oil

PCRA

# Introduction

In many industries, little attention is often paid to oil storage, handling and preparation facilities. The result? Puddles of oil near the pump house and storage tanks—an indication of leaky joints, flanges and pipelines. Clogged filters, which impose an additional duty on the pumps. And poor combustion, manifested by smoky or spluttering flames leading to high fuel consumption.

Spilt oil is an easily avoidable waste, and renders the ground slippery and dangerous. For efficient burning, foreign matter such as dust, water, coke and sludge particles in fuel oil should be removed by adequate filtration. It is also necessary to examine several aspects, such as pumpability of oil during winter months, the type and capacity of the pump, the length of the pipelines, and the sizing of pipes. Correct preheating of fuel oil prior to combustion is also important for fuel efficiency. We shall cover some of these aspects, which have a significant effect on the fuel consumption in your plant.

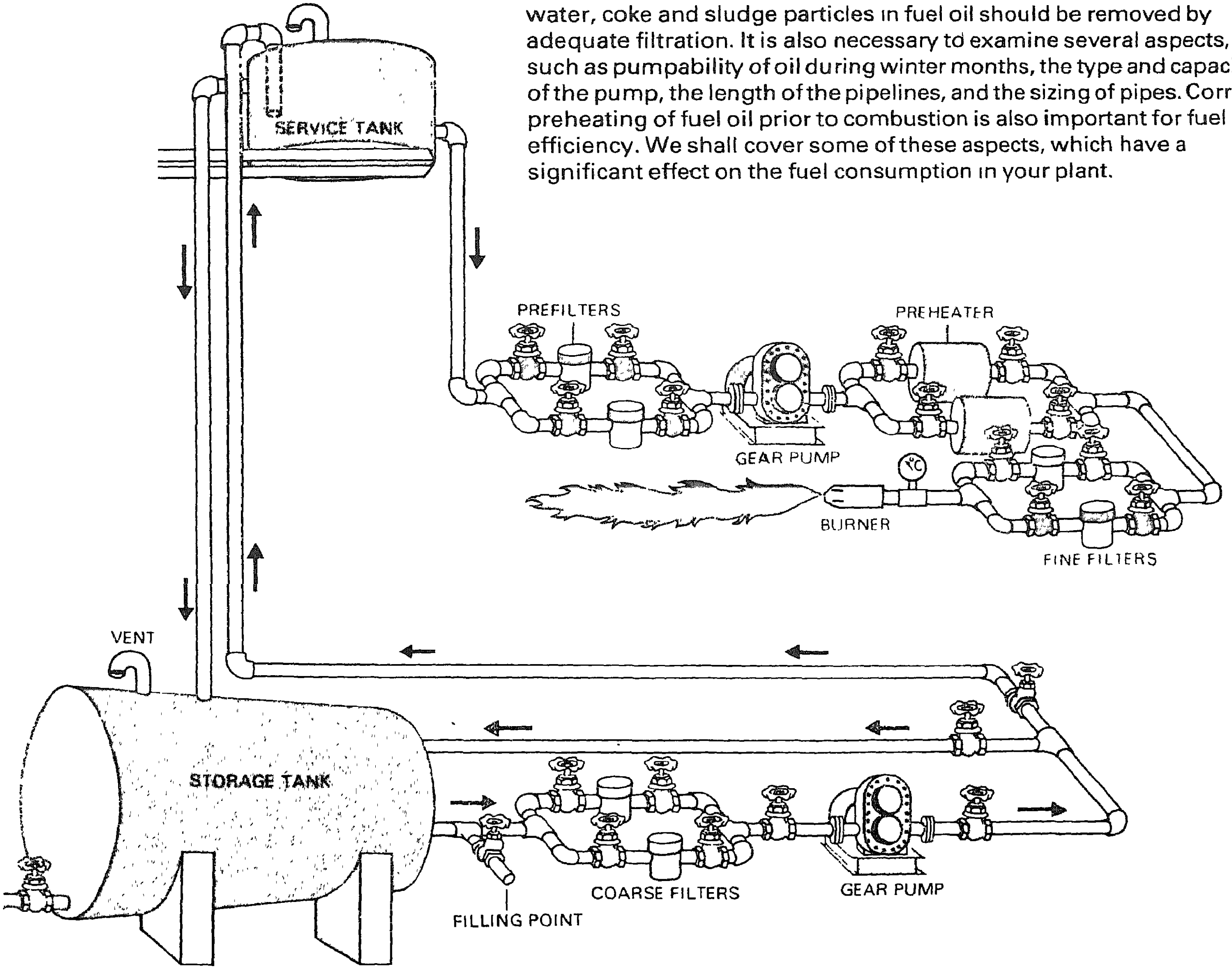


Fig. 1— GENERAL LAYOUT OF STORAGE, HANDLING AND PREPARATION OF FURNACE OIL

## Stop that leak

Spilt oil is irretrievable. A little care when oil is decanted from the tanker to the storage tanks could lead to less spillage. All leaks from joints, flanges and pipelines must be attended to at the earliest.

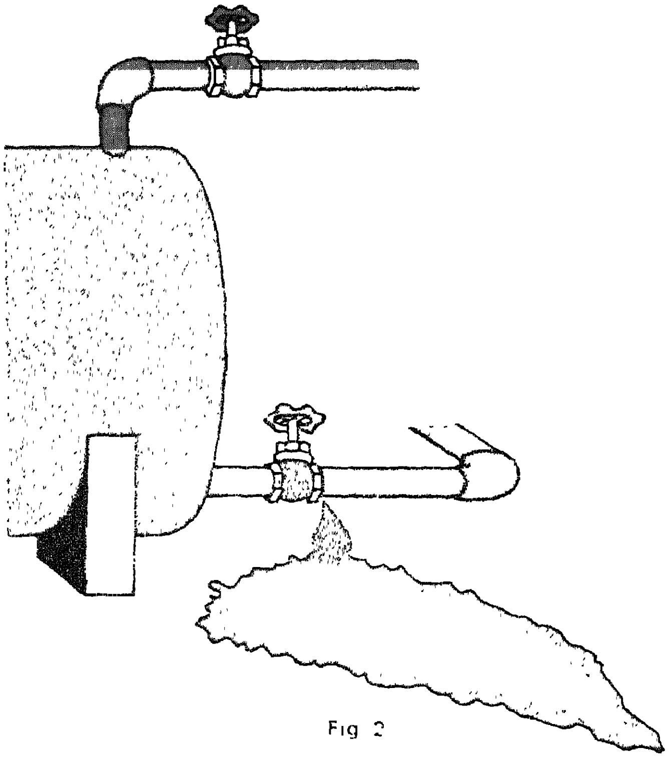


Fig 2

**Loss of even one drop every second can cost you over 4,000 litres a year.**

## How to store furnace oil

It is wrong and wasteful, even dangerous, to store oil in barrels. Furnace oil is best stored in cylindrical tanks either above or below the ground. Generally, the main storage tank is erected above ground when the capacity exceeds 70,000 litres. For lower capacities, underground storage may be more economical. When erecting a storage tank above ground, remember to maintain safety distances from the surrounding structures, as prescribed by the Explosives Department.

Storage tanks are generally made from welded mild steel plates. The overhead tank should be mounted on concrete blocks, which provide a slight gradient of 1:50 towards the drain valve.

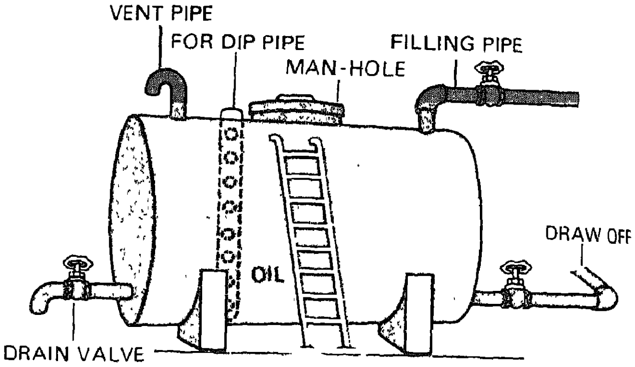


Fig 3—DETAILS OF STORAGE TANK

Each of the following fittings has a definite role to play. Perhaps your tank does not have some of them.

**The outlet or draw-off pipe** should be located at the raised tank end, no less than 15 cms. from the bottom.

**The vent pipe,** of gooseneck type, should be located at the highest point of the tank to facilitate filling by venting air an oil vapour during the filling operation. It should be at least 5 cms. in diameter and provided with a strainer at the outlet

**The fill-pipe** could be located either at the top or at the bottom of the tank. If located at the top, it must be ensure that the pipe descends almost to the bottom of the tank. When located near the bottom, it is important to position non-return valve on the line to avoid furnace oil re-entry in the tank-truck on account of back pressure. To avoid leaka of oil during decanting, it is advisable to have a camlock coupling at the filling end so that it fits snugly on the delivery hose.

**The drain pipe,** which is fitted at the lower tank end botto is used to periodically remove the accumulated water. It is difficult task to drain the water and sludge from underground storage tanks. The water and sludge which settle down at the bottom should, however, be removed a handpump. It would be advantageous to have two sucti pipes—one at a lower level and the other at a higher lev so that in case the sludge accumulation is up to the lowe point and the suction line chokes up, the alternative line could be put into operation and adequate time would be available to decide upon a time schedule for cleaning th tank.

Furnace oil as delivered may contain dust, dirt, gummy matter and water. During storage for prolonged periods these tend to form sludge which accumulates in the varic 'dead spaces' of the tank, where the oil is not agitated dur normal operations of the tank. This results in unsteady flames and clogging of filters. To avoid this, some means of agitation of oil in the tank may be necessary.

Cleaning of storage tanks, about once a year, will remove the accumulated sludge. Besides cleaning, periodic inspection and maintenance of the storage tank and auxiliaries is important.

## The service tank

In addition to the main storage tank(s), industries may have one or a number of day service tanks located in proximity to the units consuming oil.

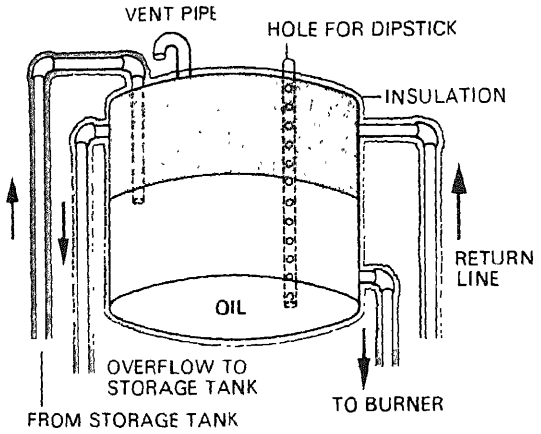


Fig. 4

The principles enumerated earlier for the maintenance of main storage tanks apply here too. The service tank may be sized for a shift's consumption or daily consumption—the choice depends on capacity required, ease of location of tank near the shop, pumping capacity, horse power, etc. Certain additional precautions may, however, be taken with respect to service tanks:

a) Service tanks should not be located very near or above furnaces, hot air or process ducts, etc.

b) They may be provided with overflow pipes which lead directly below to a sump. As a further refinement, limit switches could be provided to avoid the possibility of oil overflow.

c) In gravity feed systems, the difference in height between the service tank and the burners should be at least 10 metres.

## Why pay more for receiving less?

Do you check how much oil you actually receive? Are you paying more for receiving less? It would be worth your while to check the quantity of oil decanted into the storage tank. Road tankers are provided with dipsticks. Readings of oil level in the various compartments should be taken before decantation. The following procedure may be adopted before assessing the quantity of oil in the road tankers :-

i) Ensure that the tank lorry is parked on firm level ground.

ii) The dipstick should be checked to ensure that it is the one calibrated by the Weights and Measures Department for the compartment concerned.

iii) The dip readings of all the compartments should be checked, and shortfall, if any, can be determined by topping up of the compartments with measured quantities of furnace oil from the main storage tank.

iv) If the tank truck has been filled hot, the product in the compartment is likely to shrink to the extent of 0.7 litre/KL per degree centigrade fall in temperature. If the shortfall is higher, it may be due to pilferage.

v) Your storage tanks should also be calibrated. Though dip readings in storage tanks are more or less reliable, a major deviation should be investigated. They may provide a clue to malpractices.

## Removal of contaminants

Furnace oil should be freed from possible contaminants such as dirt, sludge and water before it is finally fed to the combustion system.

Furnace oil arrives at the factory site either in tank lorries by road or by rail. Oil is then decanted into the main storage tank. To prevent the possibility of contaminants such as rags, cotton waste, loose nuts or bolts or screws from entering the system and damaging the pump, position a coarse strainer of 10 mesh size (not more than 3 holes per linear inch) on the entry pipe to the storage tanks. Progressively finer strainers should be provided at various points in the oil supply system to filter away finer contaminants such as external dust and dirt, sludge or free carbon. It is advisable to provide these filters in duplicate to enable one filter to be cleaned while oil supply is maintained through the other. Fig. 5 gives an illustration of the duplex system of arrangement of strainers.

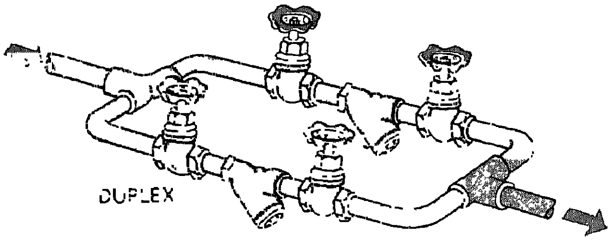


Fig. 5–ARRANGEMENT OF STRAINERS IN A PIPE LINE

**Sizing of strainers**

| Location | Strainer Sizes Mesh | Strainer Sizes Holes/Linear inch |
|---|---|---|
| Between rail/tank lorry decanting point and main storage tank | 10 | 3 |
| Between service tank and pre-heater | 40 | 6 |
| Between pre-heater and burner | 100 | 10 |

## A sluggish problem

Our problem now is only partially over. Furnace oil increases in viscosity as temperature drops, which makes handling a little difficult, particularly in winter. At low ambient temperatures (below 25°C), furnace oil is not easily pumpable.

**Recommended preheat temperature for pumping**

| Oil grade | Preheating required for easy pumping |
|---|---|
| Diesel/LDO | No heating |
| 80 Cs at 50°C (600 RW₁ at 100°F) | 10°C |
| 125 Cs at 50°C (1000 RW₁ at 100°F) | 20°C |
| 170 Cs at 50°C (1500 RW₁ at 100°F) | 25°C |
| 370 Cs at 50°C (3500 RW₁ at 100°F) | 35°C |
| LSHS | 70°C |

The preheating of oil in the storage tank to render it pumpable can be accomplished in two ways. Either the entire tank can be maintained at the pumping temperature (bulk heating) or an outflow heater may be fitted to heat the oil as it flows out. Bulk heating, which uses steam coils (Fig. 6) positioned at the floor of the tank, requires additional heat to compensate for the heat losses from the tank surface. To reduce steam requirements, it is advisable to insulate ta where bulk heating is used.

In the case of outflow heating, only the oil which leaves tank is heated to the pumping temperature.

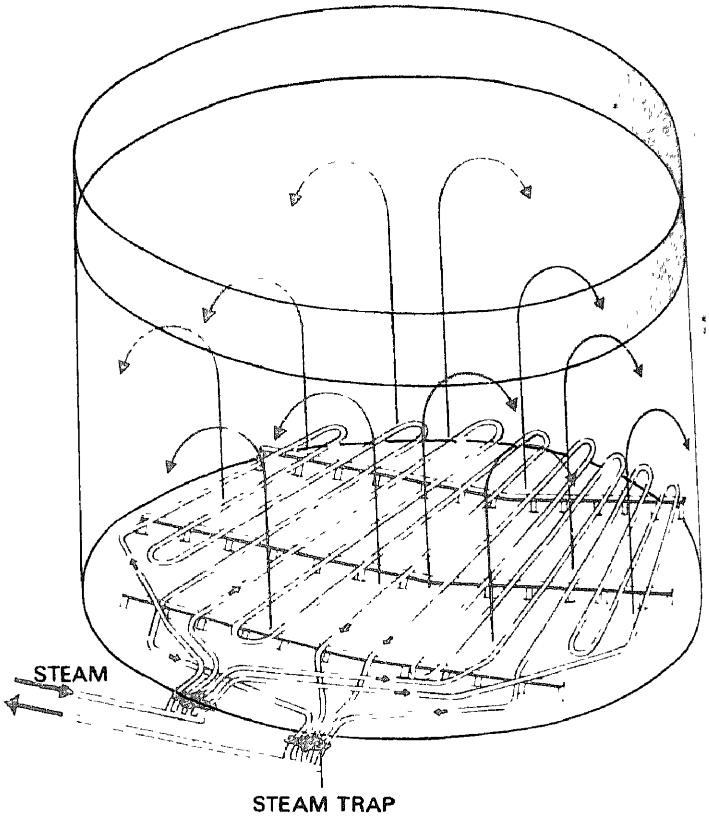


Fig 6–BULK HEATING

While the outflow heater is the preferred choice, bulk heating may be necessary where flow rates are so high th outflow heaters of adequate capacity cannot be easily installed, or when using special fuels such as low sulphu heavy stock (LSHS).

The outflow heater is essentially a heat exchanger, with steam or electricity as the heating medium. The heater protrudes from the suction connection into the oil spac (Fig.7)

**Important**

Thermostatic temperature control of the oil is necessar prevent overheating, especially when oil flow is reduce stopped. This is particularly important for electric hea ince oil may get carbonised when there is no flow and the eater is on.

Thermostats should be provided at a region where the oil flows freely into the suction pipe.

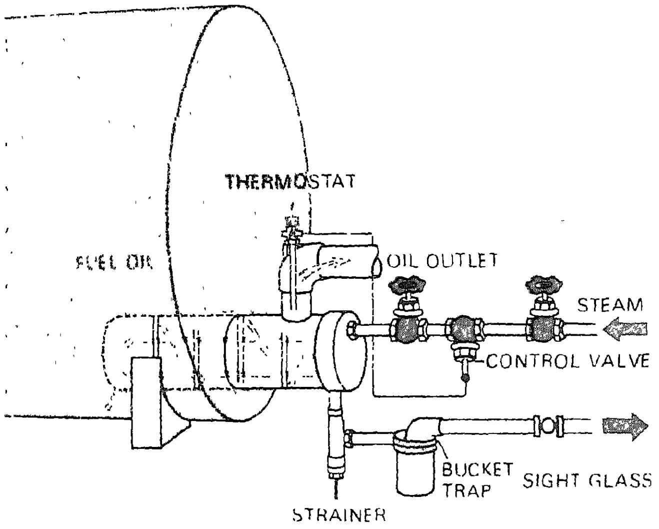


FIG. 7 – OUTFLOW HEATING

## Preparation of furnace oil for combustion

The preheating of furnace oil in the storage tanks renders it pumpable. However, furnace oil generally has to be heated further so that its viscosity is appreciably lowered to suit the burner. This operation is extremely vital if we are to ensure that furnace oil is properly atomised by the burner—an essential condition for efficient combustion. A thermometer should, therefore, be provided on the oil line.

A temperature viscosity chart could be used to obtain the correct preheat temperature. (Fig. 8) For example, manufacturers of low air pressure burners generally specify a viscosity 100 Redwood seconds No.1 at the burner tip. With the furnace oil generally marketed now (1500 Redwood seconds No. 1 at 38 C), this would need preheating around 100°C.

The oil can be preheated by either electricity or steam. The capacity of the preheater depends on the oil flow rate and the required rise in temperature.

**Oil preheater capacities for 100°C rise in temperature**

| Oil Flow rate (litres/hr.) | Preheater capacity (kw) | Steam requirements (kg/hr.) |
|---|---|---|
| 5 | 0.5 | 1 |
| 10 | 1.0 | 2 |
| 15 | 1.5 | 3 |
| 20 | 1.5 | 4 |
| 25 | 2.0 | 5 |
| 50 | 3.5 | 10 |
| Every additional 50 litres/hr. | Additional 3.5 kw is necessary. | Additional 10 kg/hr. capacity is necessary. |

It is essential that preheaters are provided with a thermostatic control to prevent oil carbonisation when flow is stopped. It would be a good practice to insulate the preheater as well as the oil delivery line from the preheater right up to the burners. During start-ups, cold oil may be present in the oil lines upstream of the preheater. It should be drained by providing suitable drain cocks on the line.

## Pump capacity

It is advisable to use a positive displacement pump such as a gear pump, for pumping furnace oil. Sometimes no oil gets transferred through the pipes because of excessive pressure drop and cavitation at the pump. A centrifugal pump is therefore, not recommended, as the oil viscosity increases, the efficiency of the pump drops sharply and the horse power required increases.

It is also necessary to size the pipelines properly so that there is no excessive pressure drop and the required oil flow rates are obtained. On expansion of facilities, the adequacy of pipe sizes for transporting larger quantities of oil should be reviewed. It is preferable to lay the oil pipelines over ground as any oil leaks would then be visible and could be quickly attended to.

Fuel oil has to be pumped from the main storage tank to the day service tank. Depending upon the desired quantity of oil to be pumped, and the distance between the storage tank and the service tanks, adequate pumping capacity will have to be provided.

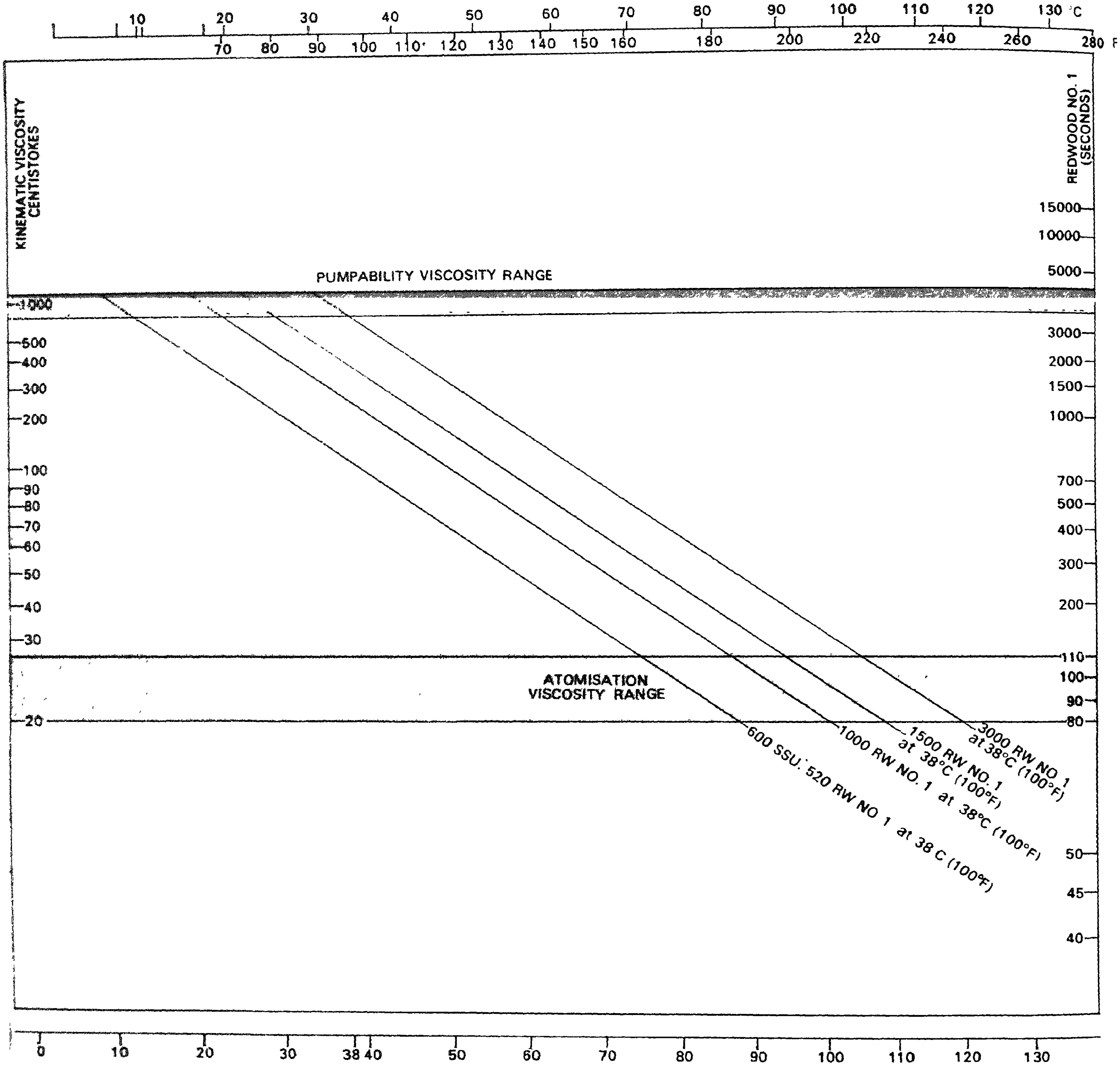


Fig. 8 — VISCOSITY—TEMPERATURE RELATIONSHIP OF FURNACE OIL

The following is a step-by-step procedure to help you in estimating the horse power requirements of your pump.

**1) Determination of equivalent length (L)**

$L = L_1 + L_2$

where:

$L_1$ = Actual length of pipeline in meters.

$L_2$ = Equivalent length of fittings in meters.

The table below gives values of equivalent length of fittings ($L_2$) for different diameters of pipes. Equivalent length of a 90-degree standard elbow on 100 mm diameter pipeline = 30 × 100 = 3000 mm = 3 metres

**2. Determination of friction loss in pipes**

This may be estimated by using the following formula:

$$h_1 = \frac{\mu L Q \times 10^3}{D^4}$$

where:

$h_1$ = Friction loss in pipes in metres.

Q = Oil flow rate is KL/hr.

D = Diameter of pipe in mm.

μ = Viscosity of oil in centistokes.

L = Equivalent length of pipeline.

**3. Determination of total head (H)**

The total head to be overcome by the pump (H) = $h_1 + h_2$

where: $h_1$ = Friction loss in pipelines in metres.

$h_2$ = Height in metres through which oil has to be lifted (difference in height between the levels of oil in the service tank and storage tank).

**4. Determination of pump horse power**

This may be arrived at by using the following formula:

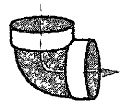
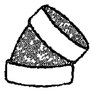
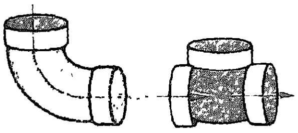
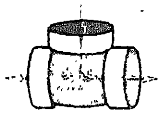
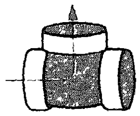
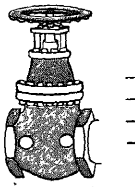
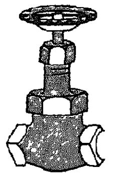
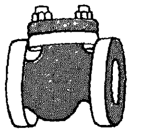
$$\text{Pump HP} = \frac{Q \times H}{270 \times \eta} \text{(Approximately)}$$

where: Q = Fuel oil flow rate in KL/hr.

H = Total head in metres.

η = Efficiency of pump (around 0.6 for gear pumps).

EQUIVALENT LENGTHS.

| FITTINGS/VALVES | | EQUIVALENT LENGTH IN PIPE DIAMETERS $\left(\frac{L}{D}\right)$ |
|---|---|---|
|  90°DEGREE STANDARD ELBOW | | 30 |
|  45°ELBOW | | 16 |
|  90° LONG SWEEP ELBOW | | 20 |
|  STANDARD TEE | | 20 |
|  STANDARD TEE THROUGH SIDE OUTLET | | 60 |
|  GATE VALVE | –3/4 CLOSED<br>–1/2 CLOSED<br>–1/4 CLOSED<br>–FULLY OPEN | 35<br>160<br>900<br>13 |
|  GLOBE VALVE, OPEN | | 350 |
|  CHECK VALVE | (CONVENTIONAL SWING FULLY OPEN)<br>CHECK VALVE (GLOBE LIFT | 135<br>350 |

# A check list

## Daily checks

1) Oil temperature at the burner.
2) Oil/steam leakages.

## Weekly tasks

1) Cleaning of all filters.
2) Draining of water from all tanks.

## Yearly jobs

1) Cleaning of all tanks.

# Remember

- **Spilt oil is irretrievable. Plug all leakages.**
- **Impurities in furnace oil affect combustion. Filter oil in stages.**
- **Oil has to be preheated to obtain the right viscosity to the burner. Provide adequate preheater capacity.**

# Trouble shooting hints

| | |
|---|---|
| **Oil not pumpable** | Viscosity too high<br>Blocked lines and filters<br>Sludge in oil<br>Leak in oil suction<br>Vent pipe choked |
| **Blocking of strainers** | Sludge or wax in oil<br>Heavy precipitated compounds in oil<br>Rust or scale in tank<br>Carbonisation of oil due to excessive heating |
| **Excessive water in oil** | Water delivered alongwith oil<br>Leaking manhole<br>Seepage in case of underground tank<br>Ingress of moisture from vent pipe<br>Leaking heater steam coils |
| **Pipe line plugged** | Sludge in oil<br>High viscosity oil<br>Foreign materials such as rags, scale and wood splinters in line<br>Carbonisation of oil |

REFERENCE:

1 The Efficient Use of Fuel—HMSO, London
2 Spirax Sarco Manual on 'Fuel Oil Heating'—Spirax Sarco Ltd., Cheltenham GL 53 8ER
3 The Storage And Handling of Petroleum Liquids—John R Hughes, Charles Griffin & Co. Ltd., London.

**This booklet is one of a series on fuel oil conservation, others in the series are listed below:**

1) Combustion of fuel oils & Burners—operation and maintenance.
2) Efficient generation of steam.
3) Efficient utilisation of steam
4) Fuel economy in furnaces and waste heat recovery.
5) Refractories.
6) Thermal insulation.

**PCRA films available for industrial sector:**

1) "Tuning of Boilers and Furnaces".
2) "Handling of Fuel Oils".
3) "Efficient Utilisation of Steam in Industries" (under production).

Set up a few years ago in anticipation of the world-wide oil crisis that's affecting us all today, PCRA seeks to promote efficient utilisation of petroleum products—in homes, in industries, in farms, on roads. Because till alternative sources of energy are found, we have to make the best use of the world's diminishing oil reserves.

P C R A

**PETROLEUM CONSERVATION RESEARCH ASSOCIATION**
Petroleum Conservation Research
Association, 1008, New Delhi House,
27, Barakhamba Road, New Delhi - 110 001.

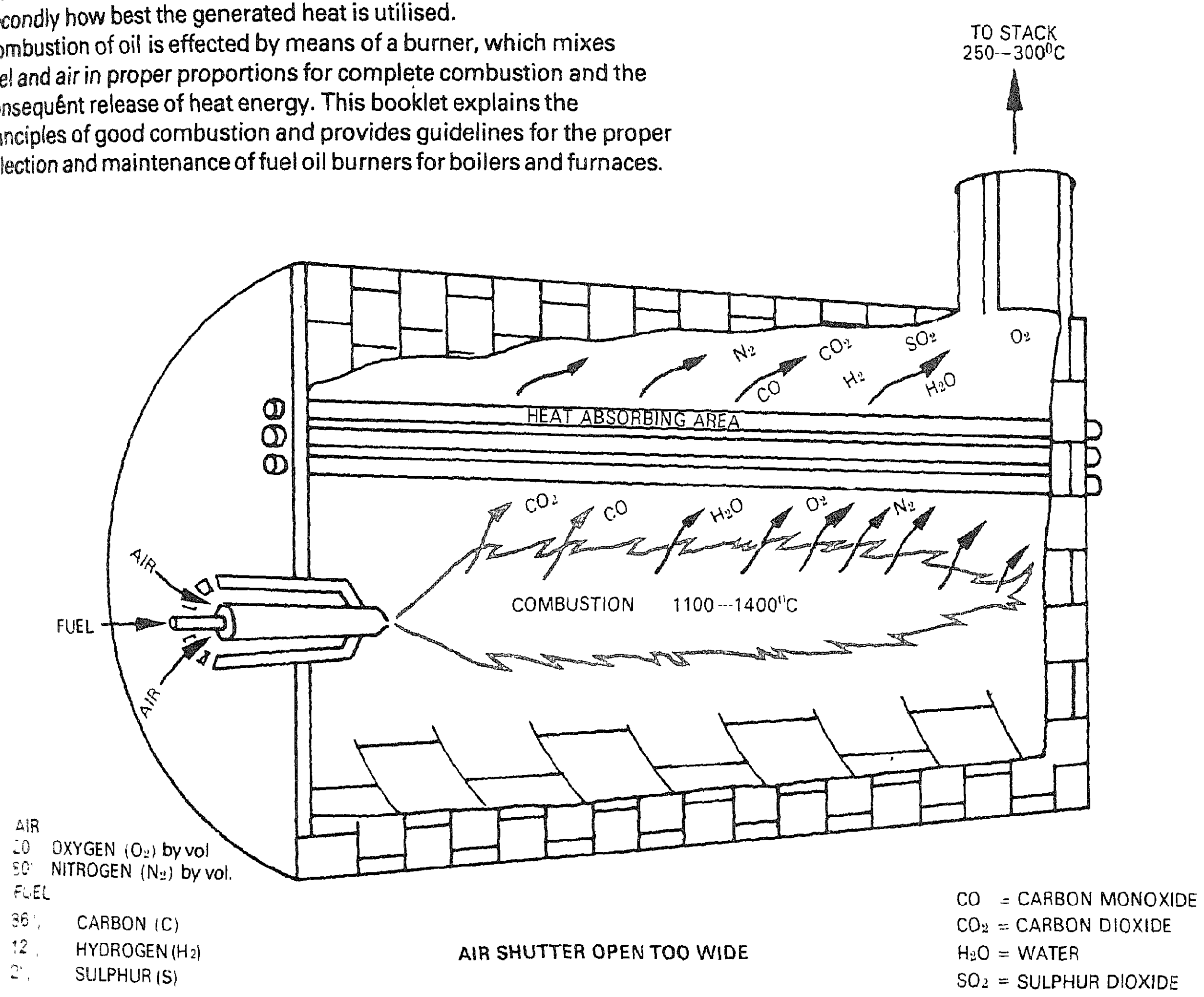
**SAVE OIL.**
**Because oil isn't going to last forever.**

# 2 Combustion of fuel oils & Burners-operation and maintenance

PCRA

# Introduction

A boiler or furnace utilises the heat generated by combustion of fuel to heat water or air or any process material. The efficiency of a boiler or furnace will depend on how efficient the combustion system is and secondly how best the generated heat is utilised.
Combustion of oil is effected by means of a burner, which mixes fuel and air in proper proportions for complete combustion and the consequent release of heat energy. This booklet explains the principles of good combustion and provides guidelines for the proper selection and maintenance of fuel oil burners for boilers and furnaces.



AIR SHUTTER OPEN TOO WIDE

(Fig 1)

# Basic combustion reactions

Carbon and Hydrogen are the principal constituents of any petroleum fuel. Sulphur is present in significantly lower percentages. In any combustion process, the reaction between fuel and Oxygen in the air releases heat energy. The combustion products are primarily Carbon Dioxide ($CO_2$), water vapour ($H_2O$) and Sulphur Dioxide ($SO_2$) which pass through the chimney along with the Nitrogen ($N_2$) in the air, as shown in Fig. 1.

After surrendering useful heat in the heat absorption area of a furnace or boiler, the combustion products or flue gases leave the system through the chimney, carrying away a significant quantity of heat with them.

Carbon, Hydrogen and Sulphur in the fuel combine with Oxygen in the air to form Carbon Dioxide, Water Vapour and Sulphur Dioxide, releasing 8084 Kcals, 28922 Kcals & 2224 Kcals of heat respectively. Under certain conditions, Carbon may also combine with Oxygen to form Carbon Monoxide, which results in the release of a smaller quantity of heat (2430 Kcals/kg of carbon).

$C + O_2 \rightarrow CO_2 + 8084$ Kcals/kg of Carbon

$2C + O_2 \rightarrow 2CO + 2430$ Kcals/kg of Carbon

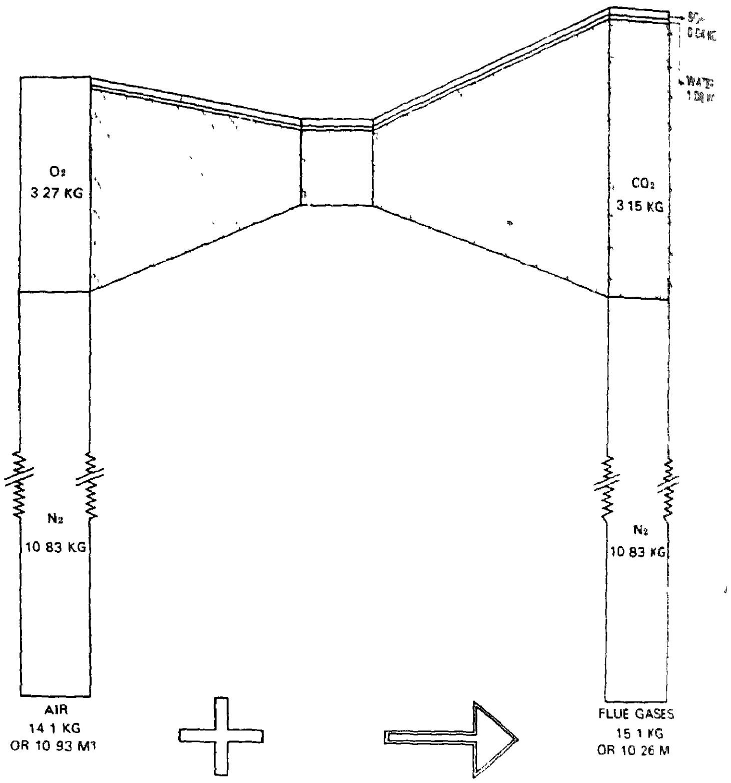
$2H_2 + O_2 \rightarrow 2H_2O + 28{,}922$ Kcals/kg of Hydrogen

$S + O_2 \rightarrow SO_2 + 2{,}224$ Kcals/kg of Sulphur

By a reaction of Sulphur Dioxide with Oxygen, if excess air is used for combustion, Sulphur Trioxide ($SO_3$) may also be formed as a combustion product.

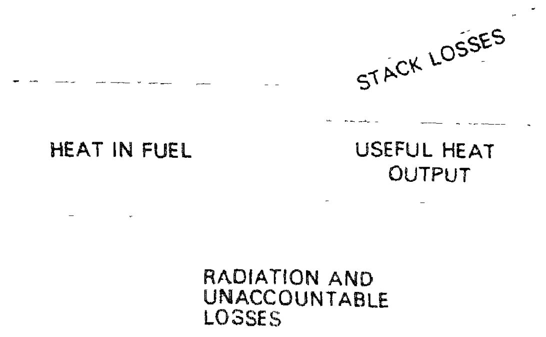
## Ideal or stoichiometric combustion

Fig. 2 shows the ideal combustion process for burning one kg of a typical fuel oil containing 2% sulphur, 86% carbon and 12% hydrogen. Use is made of theoretically required minimum quantity of air, i.e., 14.1 kg (containing 3.27 kg of Oxygen and 10.83 kg of Nitrogen). Carbon reacts with Oxygen to form 3.15 kg of Carbon Dioxide and Hydrogen reacts with Oxygen to form 1.08 kg of water. Nitrogen in the air does not take part at all in the reaction. Carbon is fully converted to Carbon Dioxide releasing full heat. In addition, Carbon Dioxide, along with Sulphur Dioxide, constitutes 15.76% by volume of flue gases.



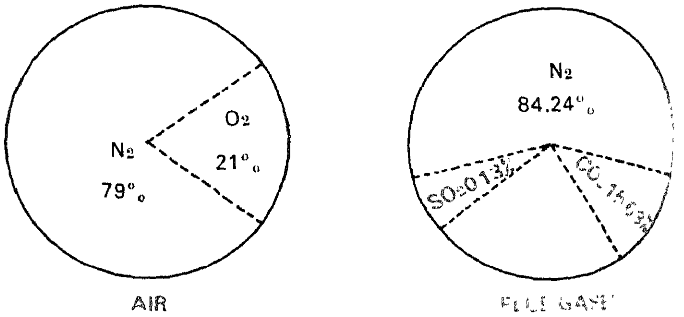
STOICHIOMETRIC COMBUSTION

(Fig.2a)



HEAT BALANCE OF A COMBUSTION CYCLE

Fig. 2

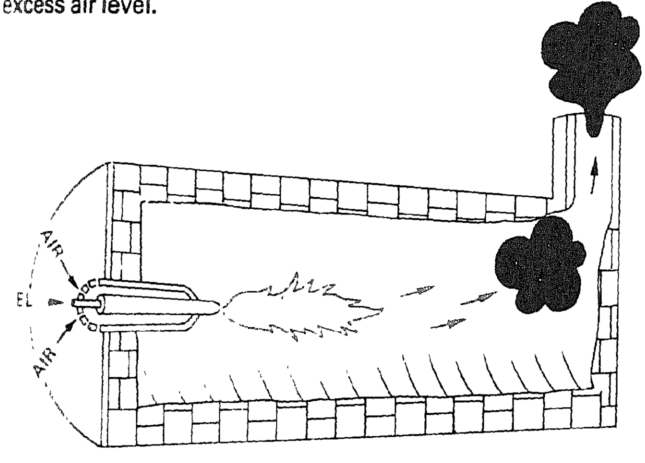


**COMPOSITION BY VOLUME**

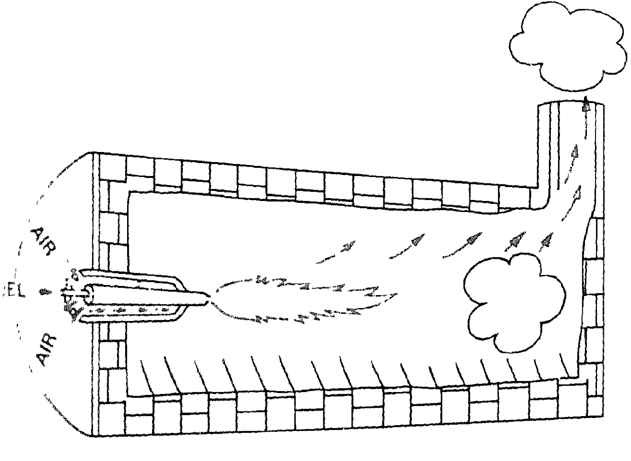
(Fig.2b)

## Optimising excess air

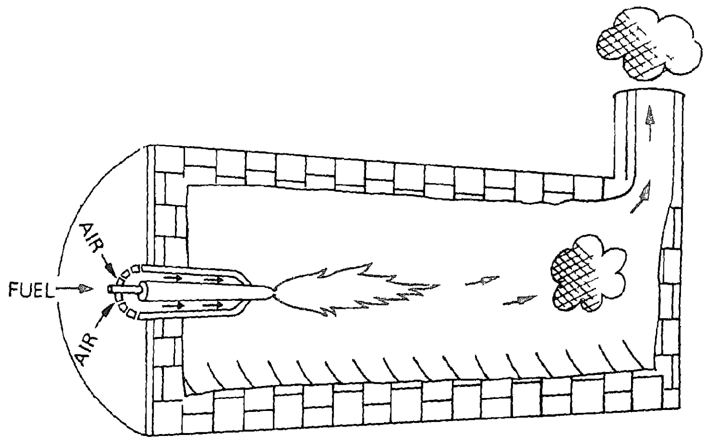
We have seen that we need 14.1 kg of air for every kg of fuel oil for complete combustion. This is the minimum air that would be theoretically needed if mixing of fuel and air by the burner is perfect. In actual practice, since mixing is never perfect, a certain amount of excess air is needed to complete combustion and ensure the release of the entire heat contained in fuel oil. If too much air than what is required for completing combustion is allowed to enter, additional heat would be lost in heating the surplus air to the chimney temperature. Less air would lead to the incomplete combustion and smoke. More air would lead to increased stack losses. Hence, there is an optimum excess air level for each type of fuel. Fuel savings are the most at the optimum excess air level.



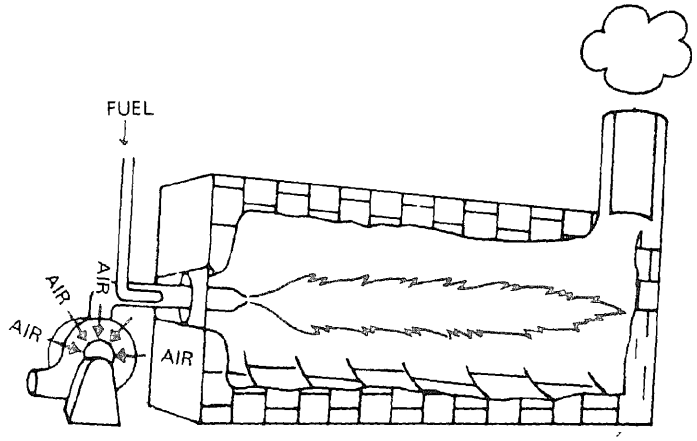
(Fig.3) TOO LOW EXCESS AIR



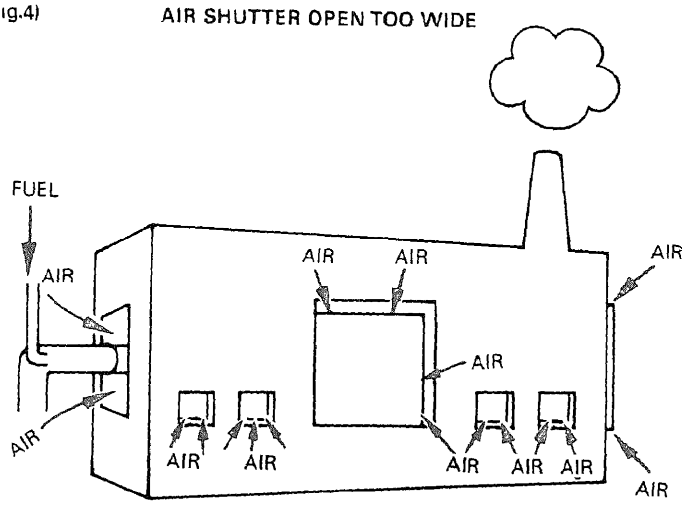
(Fig 3a) TOO HIGH EXCESS AIR



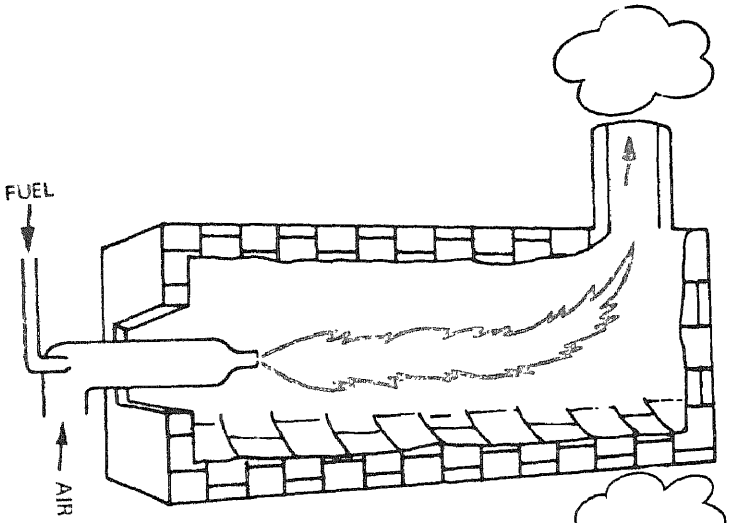
(Fig.3b) OPTIMUM EXCESS AIR



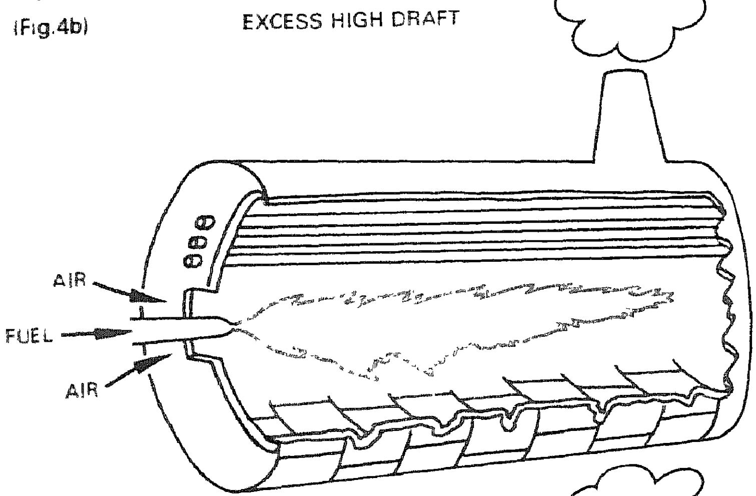
(Fig.4) AIR SHUTTER OPEN TOO WIDE



(Fig.4a) EXCESSIVE AIR LEAKS INTO FURNACE



(Fig.4b) EXCESS HIGH DRAFT



(Fig 4c) DEFECTIVE FIRE BOX

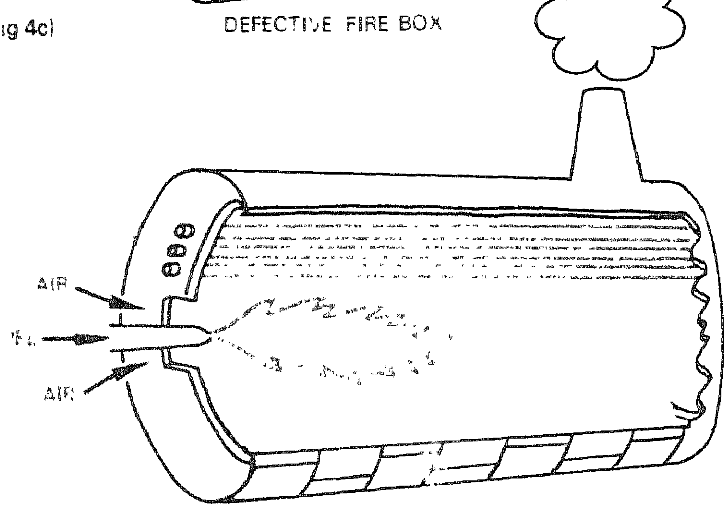
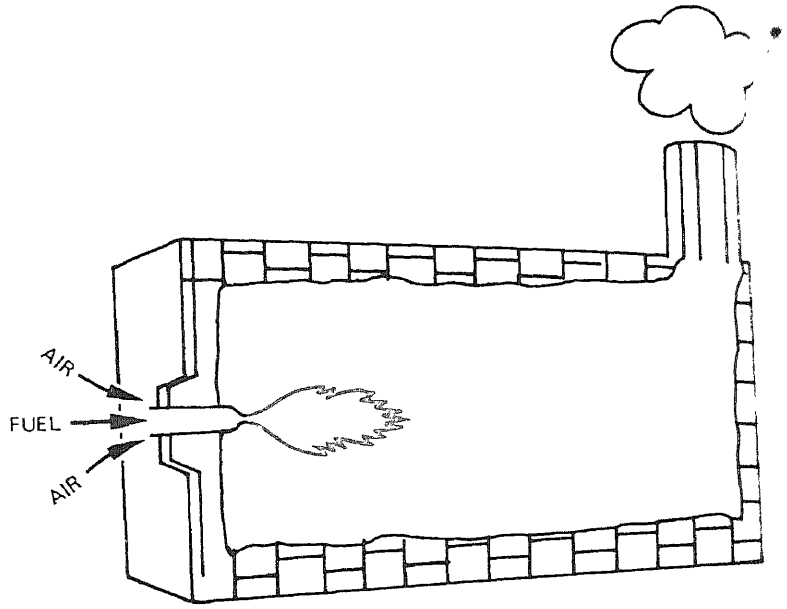
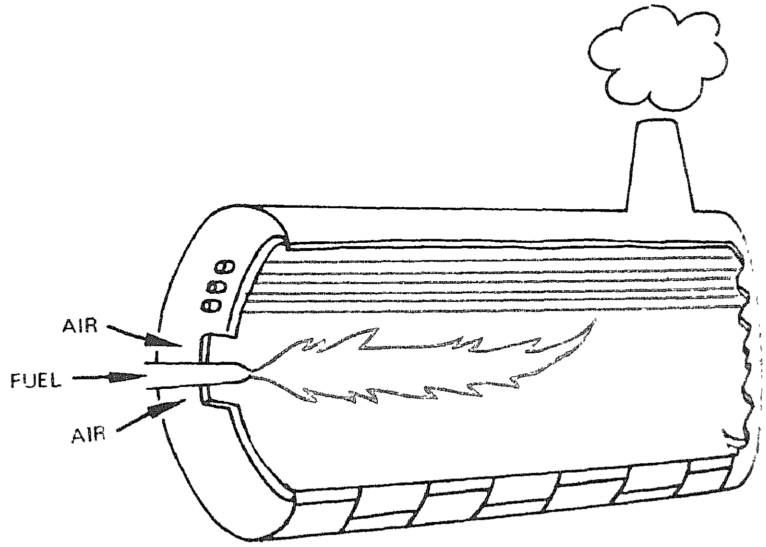


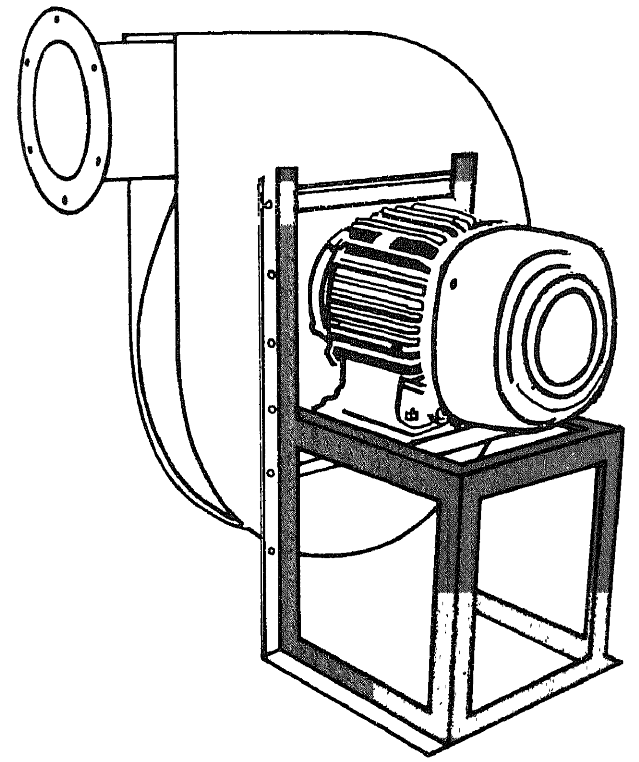
Fig 4d) WRONG FLAME SHAPE



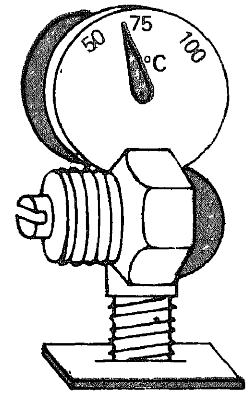
(Fig 4e) FURNACE FIRED TOO LIGHTLY



(Fig 4f) NOZZLE WORN, PLUGGED, OR UNSUITABLE FOR OIL BURNER



(Fig.4g) AIR BLOWER OF INADEQUATE CAPACITY.



ATOMIZATION OF OIL UNSATISFACTORY

(Fig.4h)

| SIZE | BURNER CAPACITY OIL IN LITRES PER HOUR | |
|---|---|---|
| | WITHOUT SECONDARY AIR | WITH SECONDARY AIR |
| 00 | 1—6.5 | 1—13 |
| 0 | 3—11 | 3—22 |
| 1 | 6—27 | 6—54 |
| 2 | 20-56 | 20—112 |
| 4 | 30—100 | 30—200 |
| 6 | 50—180 | 50—360 |

**BURNER RATING TOO HIGH**

(Fig.4i)

An experienced operator often relies on the smoke emitted by the chimney or the colour of the flame to help him adjust air at the optimum level. However, a chemical analysis of flue gases is a more objective method that helps in achieving finer air control.

CHANGES IN FLUE GAS COMPOSITION WITH EXCESS AIR

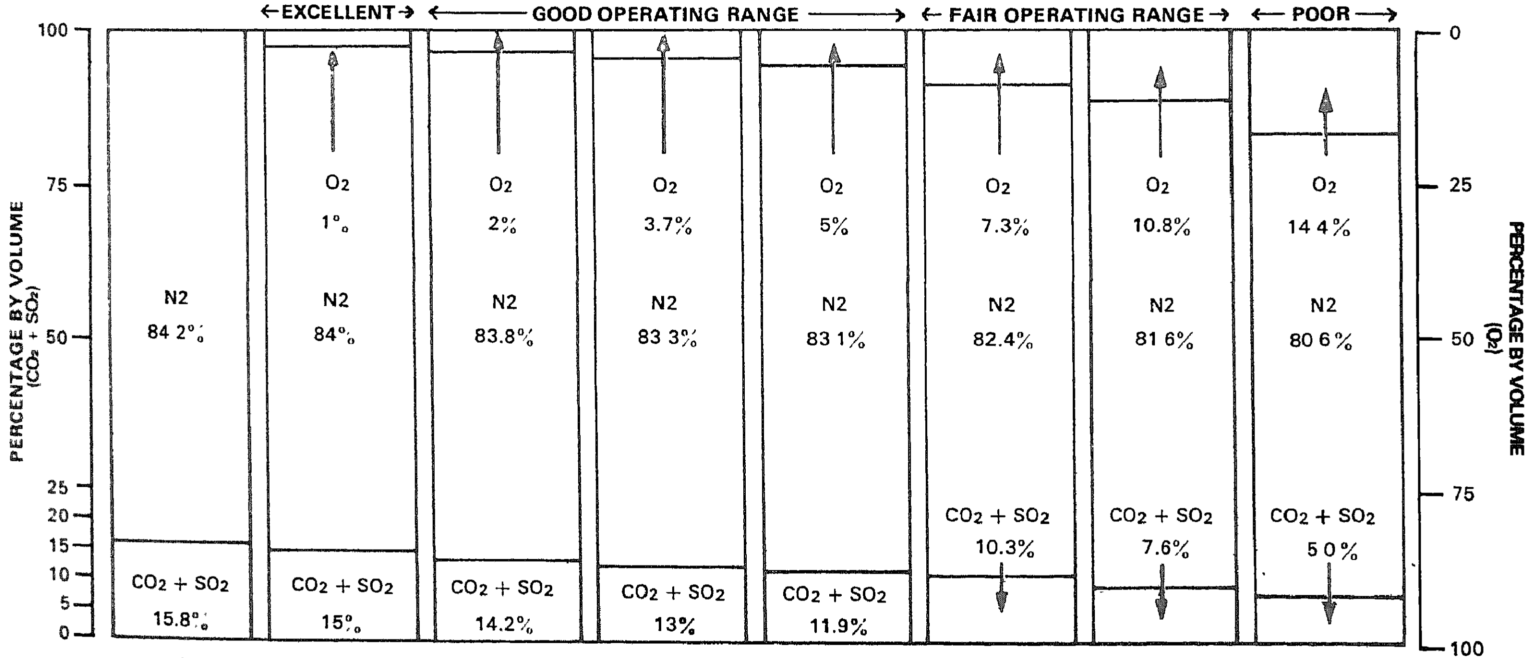
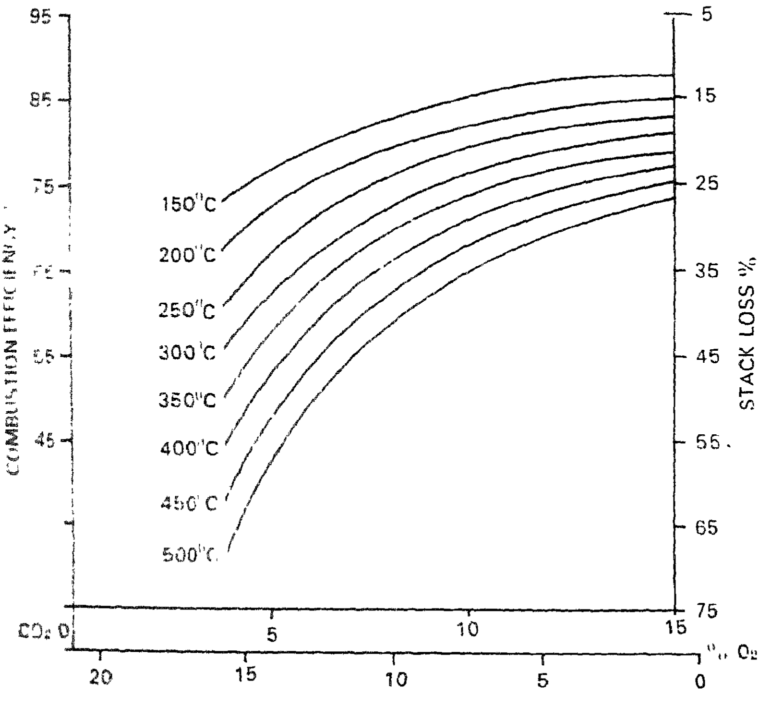


Fig 5)

By measuring either the content of Carbon Dioxide ($CO_2$) or Oxygen ($O_2$) in flue gases, it is possible to estimate the percentage of excess air in flue gases. Continuous recording instruments, as well as cheaper portable instruments are available. (See section on Flue Gas Analysis.)

In ideal combustion, Carbon Dioxide and Sulphur Dioxide together constitute 15.76% by the volume of flue gases. As excess air increases, the concentration of these gases ($CO_2$&$SO_2$) decreases and the concentration of oxygen steadily increases in the flue gases. This forms the basis for determination of excess air through chemical analysis.

If the temperature of flue gases at the point of the sample is also known, the heat content in flue gases at that point can be estimated. In case flue gas analysis and temperature are measured at the exit of the boiler or furnace, it would thus be possible to estimate stack losses from the graph shown below.



(Fig.6)

When heated, air becomes lighter and begins to rise. The higher the temperature to which the gas or air is heated, the faster it will rise. If this air is heated in a confined space as in a chimney, an upward flow is established. This phenomenon is known as draft.

In natural draft system, excess air can be controlled by dampers placed before the chimney. Measurement of draft helps in setting the damper correctly for various loads. Simple inclined tube manometers can be used to measure the draft.

It must be remembered that there is no precise relationship between the damper position and the amount of draft, i.e., a half-closed damper does not pass just half the quantity of air. As the damper is closed gradually, the draft gauge may not show any significant reduction in draft up to a certain point.

By a trial using flue gas analysis to monitor excess air levels, the correct draft for minimum excess air compatible with smokeless combustion can be determined for various loads. After calibrating the draft gauge for various loads, dampers should be operated to obtain the correct draft for that load.

## Smoke as an indicator of combustion efficiency

Excess air adjustment has a direct relationship with smoke. If a chimney emits a hazy brown smoke, the combustion is proper, but if the chimney emits black smoke, it indicates incomplete combustion and needless fuel wastage. Similarly, a chimney that emits white smoke, indicates too high excess air and hence fuel wastage.

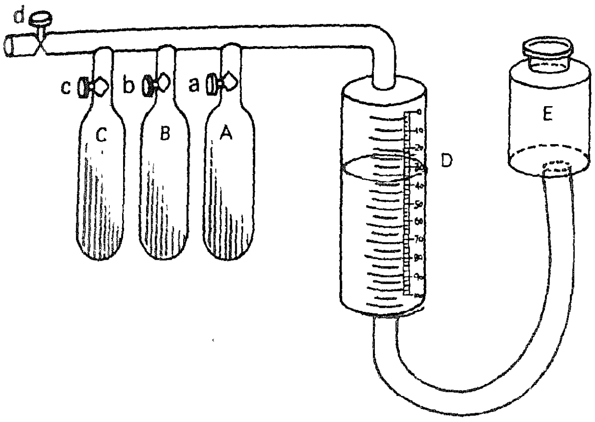
The smoke density can of course be measured by smoke meters, which compare the smoke marking on a filter paper introduced in the flue gas stream with standard markings of varying smoke intensity. Optical instruments using photo cells are also available to monitor the smoke density continuously.

## Flue gas analysis

### Orsat Apparatus

The flue gases may be analysed by means of the Orsat Apparatus.

Flask A contains a solution of Caustic Soda, which readily absorbs the Carbon Dioxide from the sample. Flask B



ORSAT APPARATUS

contains Pyrogallic Acid and Caustic Soda, which absorbs the Oxygen from the sample. Flask C contains a solution of Cuprous Chloride in Hydrochloric Acid which absorbs the Carbon Monoxide. At the entrance to each of the flasks A, B and C are cocks a, b and c; d is a three-way cock which opens to the boiler flue or to the atmosphere. The measuring tube D is graduated and is surrounded by a water jacket in order to maintain a constant temperature. The flask E is connected to the bottom of D by a long rubber tube, and which contains water. By raising the flask E, the water in it will flow into D, and thus push out any gas inside. By lowering E below the level of D, the water will flow from D back into E, thus causing a suction by which the sample is drawn into D.

**How to choose a sampling point for flue gas analysis**

- Avoid sampling at downstream or at points of air infiltration.
- Avoid sampling at dead pockets like bends or immediately downstream of dampers.
- Choose a point close to the furnace exit.
- Use the same point where exit temperature is measured for heat balance calculations.

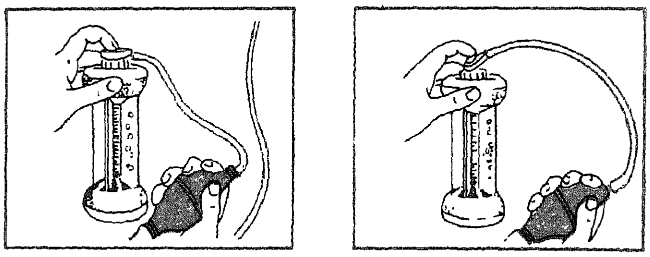
In order to test a sample of flue gas, the apparatus is connected to the furnace flue near the base of the chimney, cock d being open to the atmosphere, cocks a, b and c being closed. The flask E is held up so that there is 100 cc of water in D. Cock d is then opened to the flue, and E is lowered until a measured quantity of flue gas has been sucked into D. Cock d is now closed to both the flue and the atmosphere. Then, cock a is opened and flask E is raised until the water from E has forced the sample of gas into flask A; this will absorb the Carbon Dioxide. Pump the sample in and out of the flask several times by raising and lowering flask E. This ensures that all of the Carbon Dioxide is absorbed. The sample is now sucked back into D by lowering the flask E.

The flask E must be held in such a position that the water level in E is the same as the water level in D. This ensures a constant pressure in D while taking readings. The water level in D will now be higher than before by the amount of Carbon Dioxide absorbed; thus the volume of Carbon Dioxide in the sample may be directly read off from the graduations of tube D.

The process is now repeated with flasks B and C, from which the volume of Oxygen and Carbon Monoxide in the sample are also obtained. The amount of Carbon Monoxide absorbed is extremely small and the measurement of its volume is consequently not that reliable.

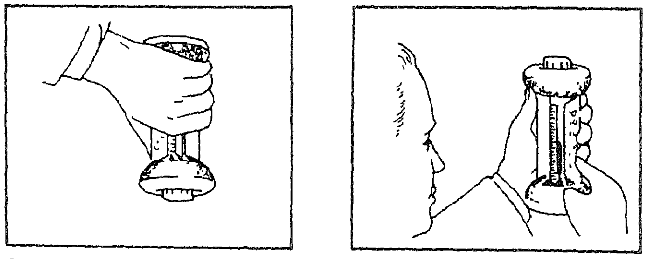
## Portable absorption analysers

The Orsat Apparatus, though fairly accurate and bulky,



1 PUSH RUBBER CONNECTOR DOWN—THEN SQUEEZE BULB 18 TIMES

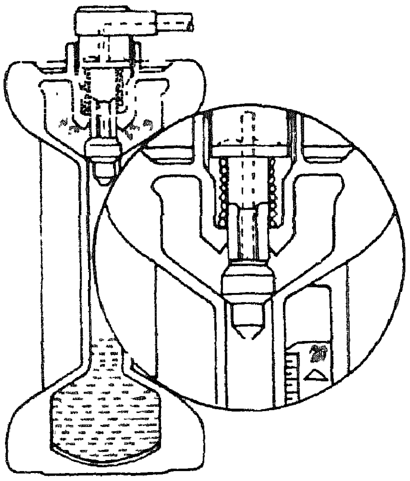
2. LIFT FINGER FROM RUBBER CONNECTOR—THIS SEALS ANALYSER



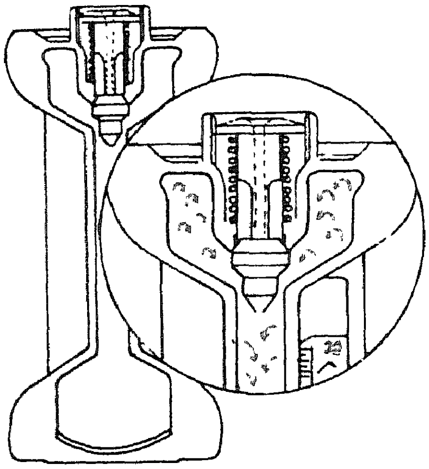
3 TURN BOTTOM SIDE UP AND BACK AGAIN , TWICE ON $CO_2$, FOUR TIMES ON $O_2$.

4. READ FLUID LEVEL ON SCALE FOR PERCENTAGE OF GAS.

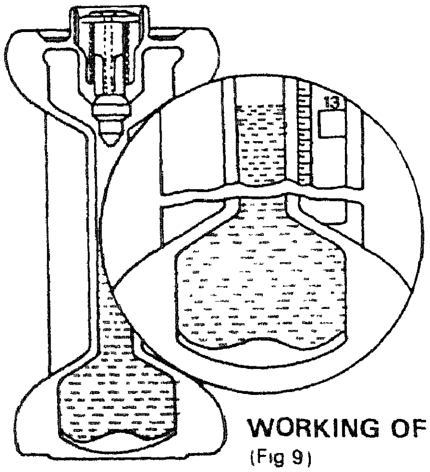
Fig. 8 **USE OF A PORTABLE GAS ANALYSER**



1 WHEN PLUNGER VALVE IS DEPRESSED, GAS SAMPLE IS PUMPED INTO TOP RESERVOIR WHILE CENTRE BORE IS SEALED OFF



2 WHEN PLUNGER VALVE IS RELEASED GAS SAMPLE IS LOCKED INSIDE THE ANALYSER AND THE TOP RESERVOIR IS OPENED TO CENTRE BORE SO THAT GAS SAMPLE CAN PASS THROUGH ABSORBING FLUID



3. ABSORPTION OF $CO_2$ $O_2$ BY FLUID CREATES SUCTION WHICH CAUSES DIAPHRAGM TO FLEX UP AND FLUID TO RISE IN CENTRE BORE TO REPLACE GAS ABSORBED

WORKING OF $CO_2/O_2$ GAS ANLYSERS
(Fig 9)

needs a skilled operator/chemist. It is hence used for sp occasional checks.

The portable analyser (See Fig. 9) also uses the chemical absorption method. It is quite handy and simp operate. A sample of flue gases is sucked or aspirated through a filter into the analyser containing caustic soda solution. The change in volume is directly read off on a calibrated scale in terms of percentage of Carbon Dioxide

A similar apparatus for measuring Oxygen using a solut of alkaline Pyragallol is also available.

## Probe type analyser

These types of analysers have come in vogue recently fo oxygen analysis in flue gases. Here, the conventional arrangement for sampling of gases is avoided and it is possible to control air-fuel ratio practically instantaneous A Zirconia Cell is incorporated in the probe. It has a tendency to develop voltage across the two sides when each side is exposed to different oxygen concentrations. B using air as the reference medium, the concentration of oxygen in the flue gases can be estimated by measuring the voltage developed.

## Other analysers

Absorption of infra-red radiation by the flue gases in variou bands is also used in advanced instruments to measure th concentration of various components of flue gases. The property of ionisation and the consequent emission of radiation can also be made use for gas analysis by using a high voltage electrical discharge in flue gases. The radiatio emitted is specific in wavelength for various gases and optical filters can be used to select the radiation of interest The magnitude of radiation is a measure of concentration c the gas of interest. Instruments based on the paramagnetic property of Oxygen, or on the electro-chemical principle, are also used to measure Oxygen content in flue gases.

## General

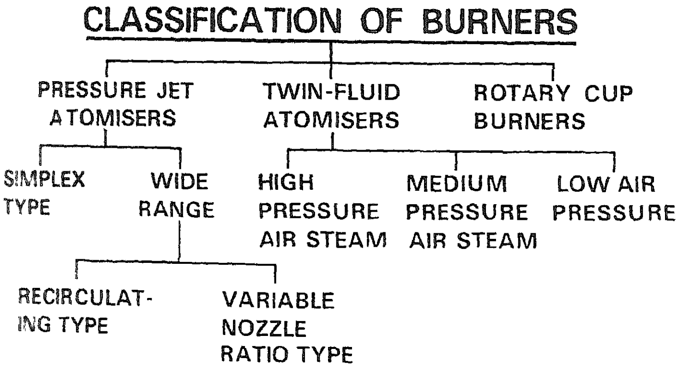
In most small and medium plants, however, adequate combustion control can be achieved with the use of simp protable instruments based on chemical absorption. The more complex on-line analysers are justifiable for larger installations where continuous monitoring and immediate control of combustion system pays good returns in terms c fuel saved.

# Burners—Operation and maintenance

The purpose of the burner is to convert the fuel oil into millions of small droplets. The process is called atomization and its principal aim is to produce a high ratio of surface to volume in the oil to facilitate evaporation and subsequent combustion. Fortunately, atomization is fairly simple to accomplish since all that is needed is the existence of a high relative velocity between the oil and the atomising air or steam. In pressure jet atomizers, a high velocity is imparted to the oil by discharging it under pressure through a fine orifice. An alternative approach is to expose the relatively slow moving oil to a high velocity stream of air or steam, the latter method is known as "twin-fluid" atomization.

# Classification of burners

The broad classification of burners may be done based on the principle used for atomization as under:



# Turn-down ratio

The relationship between the maximum and minimum fuel input without affecting the excess air level is called 'Turn-Down Ratio'. For example, a burner whose maximum input is 250,000 Kcals and minimum rate is 50,000 Kcals, has a 'Turn-Down Ratio' of 5 to 1.

In the widely-used low air pressure (LAP) burners, air at low pressure (about 24" water gauge) is provided by a blower and acts as the atomizing medium. These burners work efficiently at the designed oil flow rate but the efficiency drops sharply as the oil flow rate is reduced at low loads. It is hence necessary to avoid selection of over-sized burners of this type. Air and oil flow rates are regulated by means of valves on the respective supply lines. In the self-proportioning type, it is possible to regulate air and oil flow simultaneously by the operation of a single lever.

In medium and high air pressure burners, air for atomizing is provided by a compressor at higher pressures. When load changes, the quantity of the atomizing air is not changed and only the secondary air entering the system is regulated. Therefore, these burners have better efficiency at even low loads. The compressed air may be replaced by steam as the atomizing medium in these burners. Steam aids in the cracking of oil in the combustion zone and hence steam-assisted atomization is superior for the burning of heavy fuel oils and LSHS. Medium and high air pressure burners should be maintained carefully, since a slight increase in the nozzle size can lead to considerable waste of steam or electric power besides distortion in the spray pattern. Atomizing air forms a lower proportion of total combustion air in these burners. The atomizing air velocity is high and the combustion intensity increases proportionately. For these reasons, these burners are more popular for high temperature furnaces, where combustion air has to be preheated.

Since air at 300°C may crack the oil in the burner, only colder air is fed to the burner for atomization. Hot air is fed into the combustion chamber as secondary air.

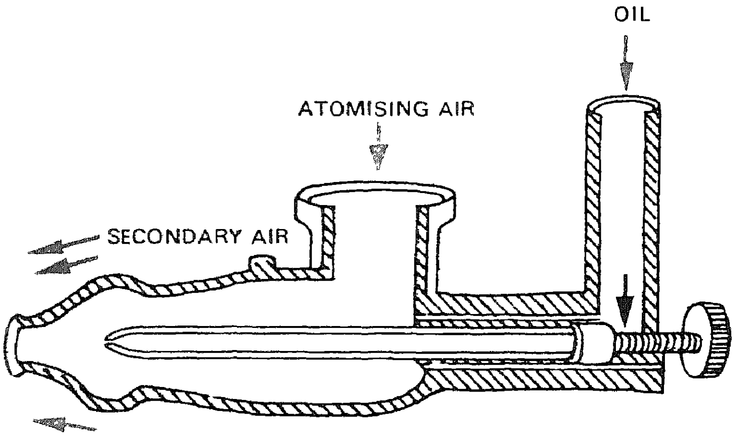
Twin-fluid atomizers are of two major types. In the common design, the fuel is injected into the high velocity air stream in the form of one or more discrete jets.

In a rotary cup burner, on the other hand, a thin film of oil is formed by injecting oil into a rapidly spinning cup. This film is converted into minute droplets as it leaves the cup, by the action of the atomizing air which is fed by the burner.

Pressure jet burners are relatively simpler and inexpensive. However, oil flow rate can be reduced in the simple design only by reducing the oil pressure and hence the quality of atomization. Efficient operation at varying loads is usually carried out by using nozzles of various jet sizes.

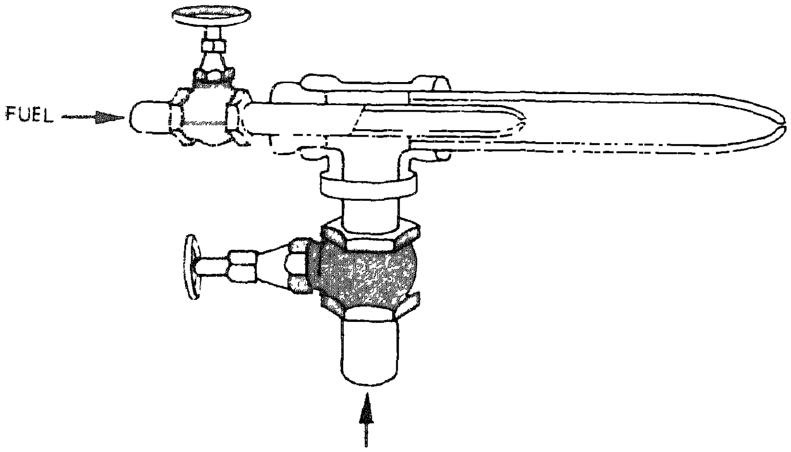
# Burner blocks

The oil that is atomized by the burner is brought up to ignition temperature in a burner block (or in the furnace, when a burner block is not provided). In a burner block, atomization, mixing with air, evaporation of the oil from the surface of the drops, cracking of oil and the start of

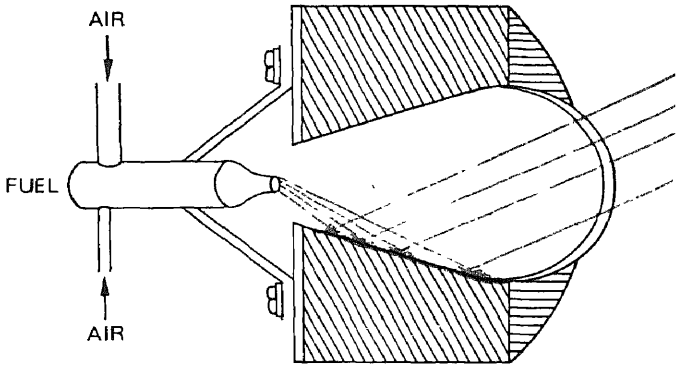


LOW PRESSURE AIR ATOMISER

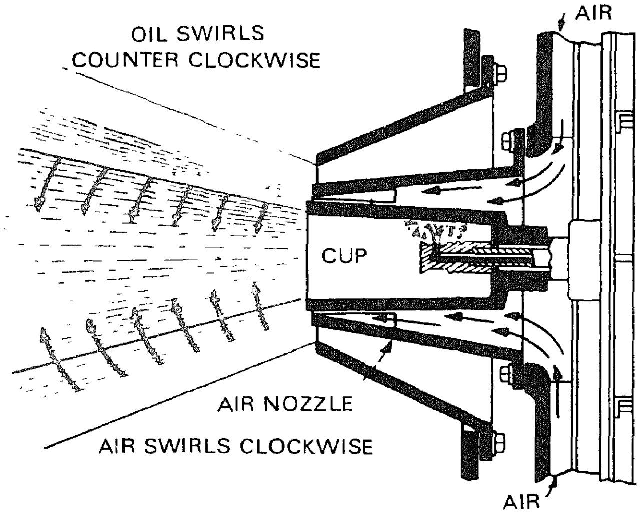
(Fig. 10)



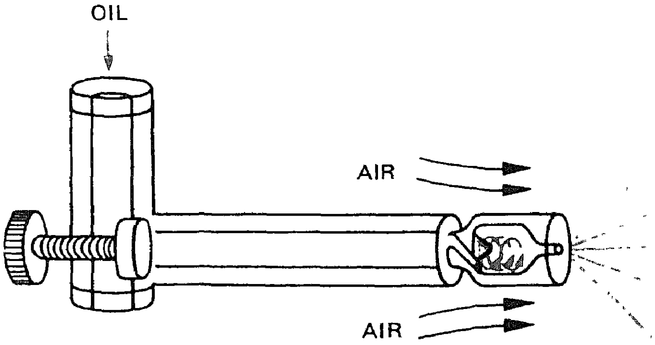
STEAM OR AIR
SIMPLE HIGH PRESSURE ATOMIZER
(Fig. 10a)



ALIGNMENT OF BURNER
(Fig. 10b)



**ROTARY CUP BURNER**
(Fig. 10c)



**PRESSURE JET ATOMISER**
(Fig. 10d)

# Burners—Operating parameters

| Type of Burner | Pressures | Turn-Down Ratio | % Air for Atomisation | Oil Viscosity at Burner tip (Redwood-Secs. -I) | Capacity Gallons/Hr. |
|---|---|---|---|---|---|
| Low Air Pressure | Oil Pressure<br>8-12 PSIG<br>AirPressure 24" W.G. | 1.4:1 (without Secondary Air)<br>5:1 (with Secondary Air) | 20–25% | 70-100 Secs. | 1/5-60 |
| Medium Air Pressure | 3 to 15 PSIG (Air) | 6:1 | 3-10% | 90-180 Secs. | 1/2-200 |
| High Air Pressure | Air Pressure<br>15 PSIG<br>Oil Pressure Higher | Small-5:1<br>Large-10:1 | 2-3% | 120-200 Secs. | 5 to 500 |
| Steam Jet | Dry Steam<br>25-175 PSIG<br>Oil Pressure<br>Nearly Same | Small-5:1<br>Large-10:1 | Steam 2-5% of Total Output | 120-150 Secs | 5 to 400 |
| Pressure Jet | Oil Pressure<br>50-200 PSIG | Simplex 2:1<br>Wide Range 6.1 to 10.1 | NIL | 70-100 Secs. | Up to 3000 |
| Rotary Cup | 1/4 to 30 PSIG | 4:1 | 15-20% | 150-200 Secs. | 3/4 to 250 |

combustion are completed. Manufacturers of oil burners adapt the cone angle in the burner block to the spray pattern of atomizing devices. Furnace builders sometimes provide additional refractory pieces for directing the flame. It is necessary to maintain the shape of the block and repair where it is damaged. While mounting the burner, care should be taken to align the burner with respect to the block so that the spray or flame does not touch the refractory and see that it is properly directed.

An additional function of the burner block is to protect the oil nozzle from furnace radiation. The block should be sufficiently long and not too wide to minimize the incidence of radiation. At the same time, it should be ensured that the flame does not impinge on the block, as that could lead to clinker formation on the block.

## Factors affecting selection of burners

There is a wide variety of burner types to choose from for any combustion installation. Satisfactory operation depends to a large extent on the selection of the correct type of burner for an individual case. The choice usually depends upon five main factors:

### i) Range

The range over which the burner will be expected to operate i.e. the ratio of maximum to minimum fuel consumption (also called 'Turn-Down Ratio).

### ii) Temperature conditions in the combustion chamber

In a process involving high combustion temperature, which can be obtained only by burning the fuel with highly preheated air, there is a limit to the temperature of the air which can safely be passed through the burner; in such cases the arrangement must be made to take the greater part of the hot air direct to the combustion chamber. Hence the amount of cold air passing through the burner must be kept to a minimum and for this type of application, a high pressure air or steam atomizing blast burner will be the correct choice. For such applications, the quality of atomization may be relatively less important and coarse atomization may in certain cases be tolerated if it is required to extend the flame down to a very hot combustion chamber. For very high temperature furnaces, the burner mainly serves the purpose of an ejector of fuel only, the temperature of the environment itself ensures that the fuel will ignite and burn completely.

But some chambers are much colder than the flame, a typical example being the flue tube of a shell boiler. In spite of the high rate of heat transfer from the flame, the walls remain at a temperature virtually that of surrounding water in the boiler. The high rate of heat transfer from the flame to cold wall results in a rapid cooling of the flame, hence the combustion must be quick and complete, i.e. atomization must be good, and air and oil droplets mixing should be very efficient.

### iii) Shape of flame

It is comparatively easy to design a blast burner to give away flame desired from a long and narrow passage with an included angle of (say) 20° to a very wide sunflower type of flame with an included angle of 180°. The wider the flame easier it is to introduce the air among the oil droplets and effecting good mixing. The atomizing air and the air sucked into the root of the flame by the ejector action are together usually sufficient to initiate the combustion, the remainder of the air is gradually sucked into the flame as the combustion proceeds.

In the case of pressure jet atomizers, the spray angle is to a large extent associated with the quality of atomization and it is difficult to obtain a narrow-angle spray from a pressure jet atomizer without sacrificing the quality of atomization. In the case where a burner of pressure jet type is selected for small diameter flame tube, it is necessary to use the momentum of the incoming combustion air to blend with the natural trajectory of the oil droplets to get a flame of narrow shape. For such propositions, if a pressure jet burner is selected rather than a blast burner, it should be supplied with a forced draft to ensure a reasonable air velocity through the air register.

### iv) Combustion intensity

To obtain a high rate of heat release, the combustion process must be expeditious. This is achieved by fine atomization and high momentum of the combustion air. High combustion intensity is, therefore, obtained at the expense of auxiliary power. In certain cases, high combustion intensity results in improvement in thermal efficiency of the system, which outweighs the loss equivalent to the auxiliary power used for the expenses incurred.

### v) Local conditions and facilities

Local conditions and support facilities also have a definite bearing on the selection of burner(s) for a plant to have normal functioning. There may be limitations on the part of providing required facilities like steam and compressed air, etc. For example, in a re-rolling mill, one may not be able to use a 'steam jet' burner, as it requires steam at certain pressure, even though it has been selected based on various other factors. In that case, one may have to go in either for 'low air pressure' or 'medium air pressure'—air blast burners, as the second best choice considering all the factors.

## Trouble shooting chart for combustion

| Complaint | Causes and Remedies |
|---|---|
| **1) Starting difficulty** | 1) No oil in the tank. |
| | 2) Excessive sludge and water in storage tanks. |
| | 3) Oil not flowing due to high viscosity/low temperature. |
| | 4) Choked burner tip. |
| | 5) No air. |
| | 6) Strainers choked. |
| **2) Flame goes out or splutters.** | 1) Sludge or water in oil. |
| | 2) Unsteady oil and air pressures. |
| | 3) Too high a pressure for atomizing medium which tends to blow off the flame. |
| | 4) Presence of air in oil line. Look for leakages in suction line of pump |
| | 5) Broken burner block, or burner without block. |

| | |
|---|---|
| **3) Flame flashes back.** | 1) Oil supply left in 'on' position after air supply was cut off during earlier shut off.<br>2) Too high a positive pressure in combustion chamber.<br>3) Furnace too cold, during starting, to complete the combustion (when temperature rises, unburnt oil particles burn.)<br>4) Oil pressure too low. |
| **4) Smoke and soot.** | 1) Insufficient draft or blower of inadequate capacity.<br>2) Oil flow excessive.<br>3) Oil too heavy and not preheated to the required level.<br>4) Suction air holes in blower plugged.<br>5) Chimney clogged with soot/ damper closed.<br>6) Blower operating at too low a speed. |
| **5) Clinker on refractory.** | 1) Flame hits refractory since combustion chamber is too small or burner is not correctly aligned.<br>2) Oil dripping from nozzle.<br>3) Oil supply not 'cut off' before the air supply during shut-offs. |
| **6) Coking of fuel in burner.** | 1) Nozzle exposed to furnace radiation after shut-off.<br>2) Burner fed with atomizing air over 300°C.<br>3) Burner block too short or too wide.<br>4) Oil not drained from nozzle after shut off. |
| **7) Excessive fuel oil consumption.** | 1) Improper ratio of oil and air.<br>2) Burner nozzle oversized.<br>3) Excessive draft.<br>4) Improper oil/air mixing by burner.<br>5) Air and oil pressure not correct.<br>6) Oil not preheated properly.<br>7) Oil viscosity too low for the type of burner in use.<br>8) Oil leaks in oil pipelines/ preheater. |

# Step-by-step Procedure for efficient operation of burners

### 1) Start Up

a) Check for correct sized burner/nozzle.
b) Establish air supply first (Start blower). Ensure no vapour/gases are present before light-up.
c) Ensure a flame from a torch or other source is placed in front of the nozzle.
d) Turn ON the (preheated) oil supply (Before start-up drain off cold oil).

### 2) Operations

a) Check for correct temperature of oil at the burner tip (consult viscosity Vs. temperature chart).
b) Check for the correct air pressure for the LAP burners (25" to 30" w.g. or 63.5 cm to 76.2 cm air pressure is commonly adopted).
c) Check if oil is dripping near the burner.
d) Check for flame fading/flame pulsations.
e) Check for positioning of burner (ensure no flame impingement on refractory walls or charge).
f) Adjust the flame length to suit the conditions (ensure the flame does not leap out of the furnace).

### 3) Load Changes

a) Operate both air and oil valves simultaneously (If it is a self-proportioning burner, operate the self-proportioning lever. Do not adjust valve only in oil line).
b) Adjust burners and damper for a light brown (hazy) smok from chimney and at least 12% Carbon Dioxide.

### 4) Shut Down

a) Close oil line first.
b) Shut the blower after a lapse of few seconds (ensure gases are purged out of the Combustion Chamber).
c) Do not expose the burner nozzle to the radiant heat of the furnace. (When oil is shut off, remove burner/nozzle or interpose a thin refractory between nozzle and furnace).

**Important**

**Burners should be dismantled and cleaned periodically, preferably once in a shift (always keep spare burners ready).**

REFERENCE:

1. The Efficient Use of Fuel—HMSO, London.
2. Fuels & Fuel Technology—Wilfred Francis, Pergamon Press.
3. Domestic And Commercial Oil Burners—Charles H. Burkhardt, McGraw-Hill Book Co.

**This booklet is one of a series on fuel oil conservation, others in the series are listed below:**

1) Storage, handling and preparation of fuel oil
2) Efficient generation of steam.
3) Efficient utilisation of steam.
4) Fuel economy in furnaces and waste heat recovery.
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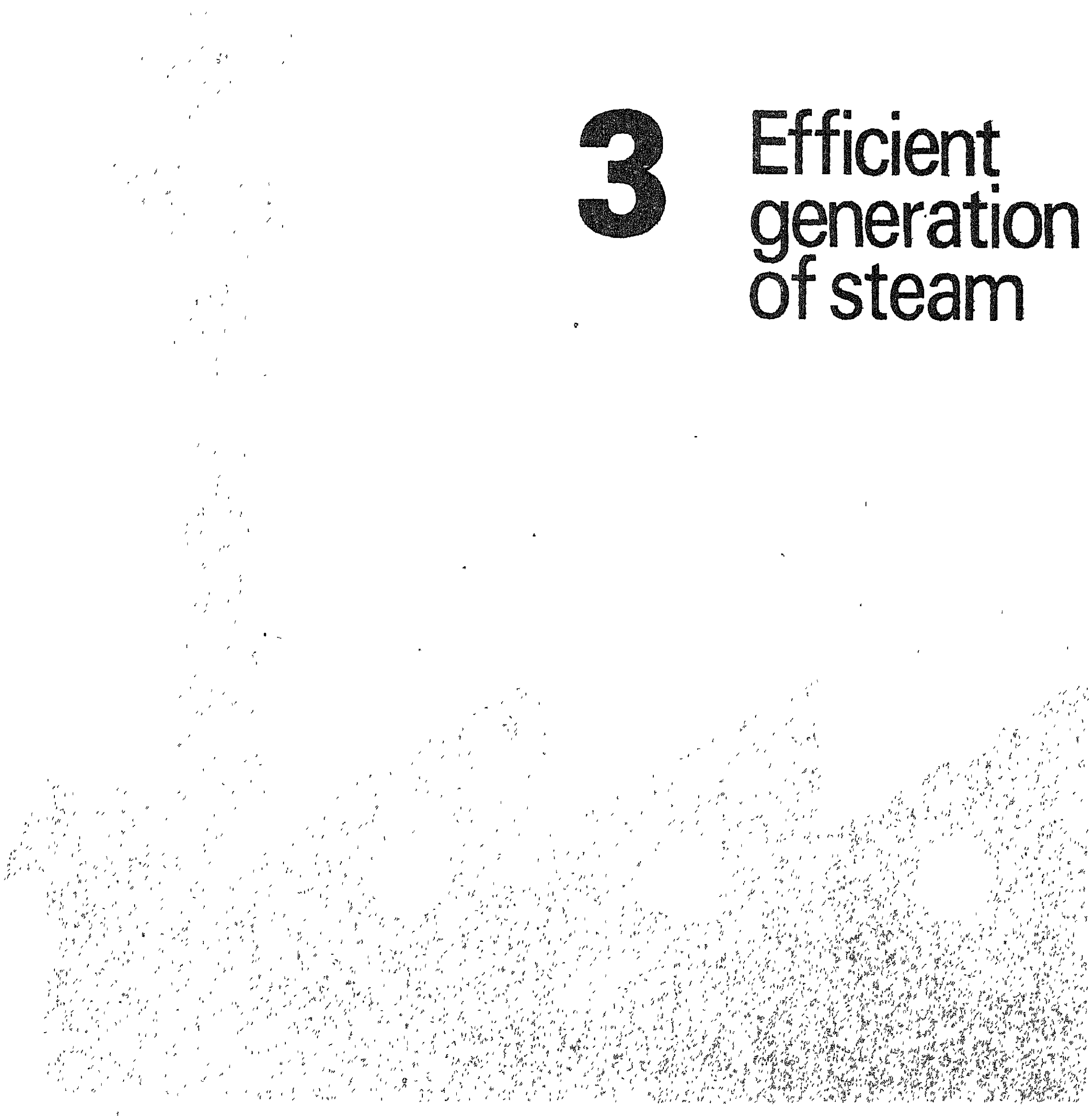
# 3 Efficient generation of steam



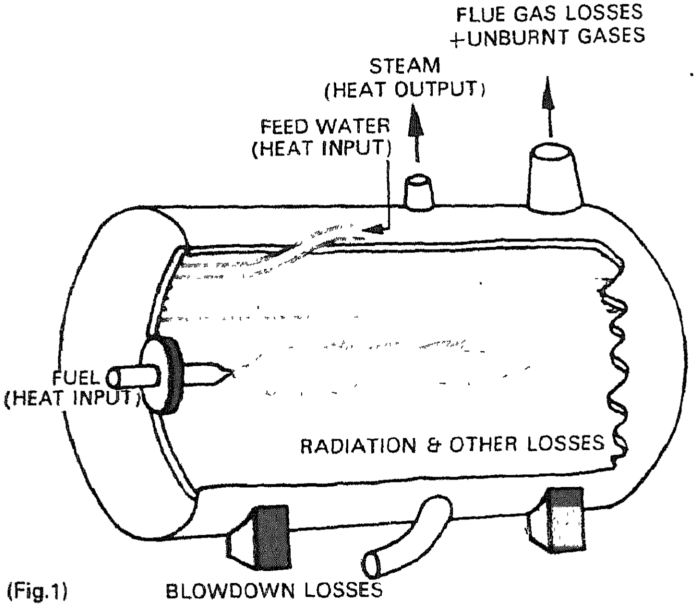
PCRA

# Introduction

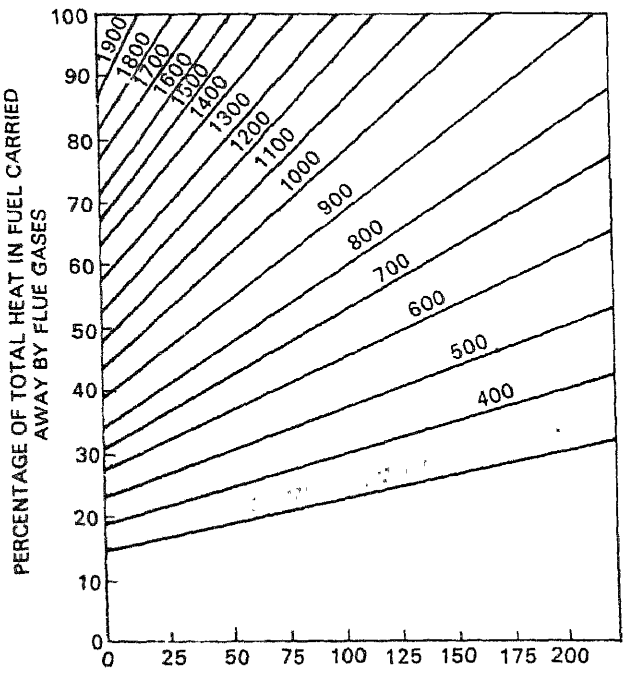
Two out of three litres of fuel oil consumed in industrial units in India is for raising steam in boilers. In many industrial establishments, the largest, and at times the sole consumer of fuel oil, is the boiler house. Hence, it is important for the industrial user of boilers to know how to economise on fuel oil consumption.

# Heat balance of boilers

A heat balance of boiler indicates what type of heat losses occur and how important they are. Construction of such a balance for each boiler is hence the first step to identify areas for improvement.



(Fig.1)



(Fig 2)

# Sensible heat in flue gases

This loss is the largest in a boiler and represents the heat carried away by the hot gases leaving through the chimney If more air than what is required for efficient combustion is allowed to enter the boiler furnace, additional heat would be lost in heating the excess air to the chimney temperature Therefore, necessary efforts have to be made not only to keep chimney temperature as low as possible but also to minimise excess air from entering the combustion chambe by proper tuning of boiler and burner operations.

# Radiation losses

Radiation losses depend on the temperature of the boiler's external surfaces. The quantity of heat lost by radiation from these surfaces is nearly independent of the load at which the boiler operates. When a boiler is operated at low loads, radiation losses may account for a significantly high proportion of the total boiler losses. Boilers with poor insulation and poor design characteristics tend to have higher radiation losses and these losses increase in such boilers rapidly at low loads. If a number of boilers are used to meet the steam demand, it is important to allocate the load among the different boilers judiciously to reduce total losses.

# Unburnts in flue gases

Fuel oil contains Carbon and Hydrogen which, on combustion are converted into Carbon Dioxide and water vapour releasing large quantities of heat. If, however, combustion is incomplete, the carbon may be converted into Carbon Monoxide which results in a liberation of only 52% of the total heat in the fuel. Under very poor combustion conditions, unburnt fuel may leave through th chimney carrying away the entire heat content of the oil vapours. The key to complete combustion is the proper filtration and preparation of fuel oil (See booklet on Storag handling and preparation of fuel oil) and proper operatio of burners (See booklet on Combustion of fuel oils and Burners–operation and maintenance.)

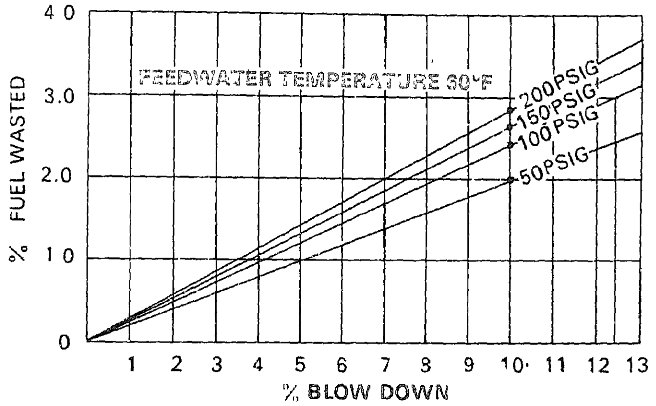
## Incomplete combustion

$C + O_2 \rightarrow CO_2$ +8,084 KCAL/KG OF CARBON
$2C + O_2 \rightarrow 2CO$ +2,430 KCAL/KG OF CARBON
FOR EVERY KG OF UNBURNT CARBON, 8084 KCALS OF HEAT IS LOST.

**For every kg of carbon partially oxidized to carbon monoxide, 5,654 Kcals of heat is lost. Incomplete combustion also leads to serious pollution (smoke and carbon monoxide).**

## Blow down losses

Dissolved salts enter the boiler through the make up water which is fed to it. The water evaporates continuously leaving behind the salts in the boiler. This leads to a continuous increase in the concentration of these salts in the boiler drum. These salts tend to precipitate beyond a point leading to the formation of scales. Water from the boiler drum should be regularly blown down to avoid concentration rising beyond such limits. Since the drum water is at high temperature, excess blow down however, leads to needless waste of fuel.

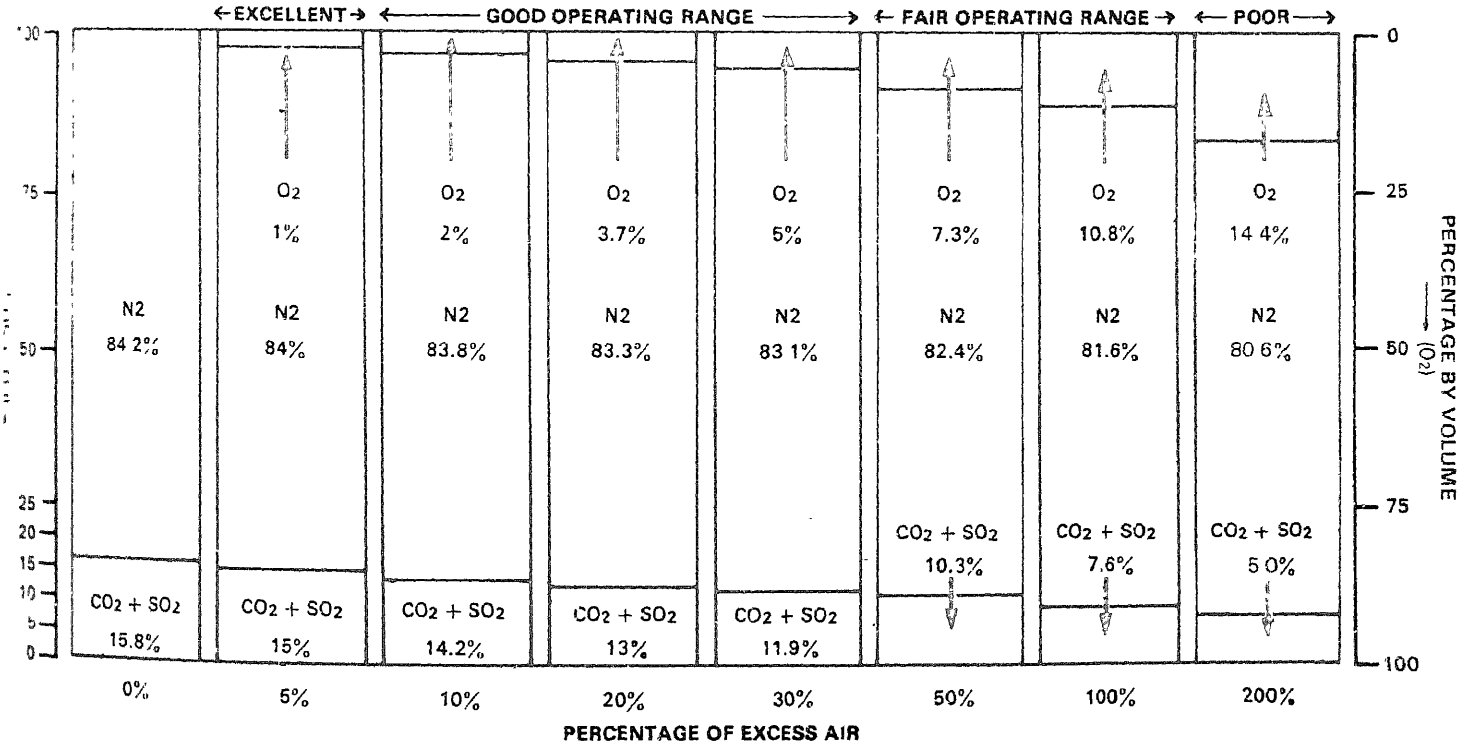


(Fig.3) — **HEAT LOSS DUE TO BLOWDOWN**

## Excess air and its control

We have seen the need for avoiding more air, than is required for combustion, from entering the boiler furnace. Air entering the boiler furnace can be controlled by proper operation of burners and through flue gas dampers. If,

**CHANGES IN FLUE GAS COMPOSITION WITH EXCESS AIR**



(Fig.4)

however, too little air is fed into the combustion chamber, combustion may be incomplete, leading to smoke and unburnts in flue gases. The key to correct air control is hence the feeding of the minimum quantity of air required for smokeless combustion.

A chemical analysis of flue gases is an invaluable aid to determine excess air levels. By measuring either the content of carbondioxide ($CO_2$) or oxygen ($O_2$) in the flue gases, it is possible to estimate the percentage of excess air in the flue gases. Continuous recording instruments as well as cheaper portable instruments for this purpose are available. (See booklet on Combustion of fuel oils and Burners—operation and maintenance.)

## Tuning of boilers

We have to first determine excess air levels by measuring the percentage of $CO_2$ in the flue gases when the boiler is running at normal firing rates. Sample locations immediately down-stream of bends, dampers, or induced draft fans should be avoided for flue gas analysis. Make sure that there is no air infiltration at the upstream of the sample point. To start with, deliberately operate the boiler at higher excess air levels so as to achieve a low $CO_2$ reading (typically 6 to 7%). Reduce air quantities slowly and monitor $CO_2$ readings. Continue reducing the combustion air until you get good $CO_2$ reading (preferably between 12 to 14%) in the flue gases. Any further reduction of air beyond 14% would result in smoke and should be avoided. A light brown haze at the top of the chimney indicates proper combustion. The boiler operator should be trained to follow this method to achieve high $CO_2$ readings at all the firing rates encountered in the boiler.

## A pre-tuning checklist

Before tuning a boiler, several preliminary checks should be made for getting best results. The following checklist will help in this task

1) Are the following as per manufacturer's recommendations?
    a) Oil pressure at the burner?
    b) Combustion air pressure?
    c) Temperature of oil at the burner tip?
2) Is the burner aligned and mounted properly?
3) Is the burner block properly mounted, aligned and clean?
4) Are the air registers in good condition?
5) Is the exhaust gas temperature within 30°C of the boiler manufacturer's design value?

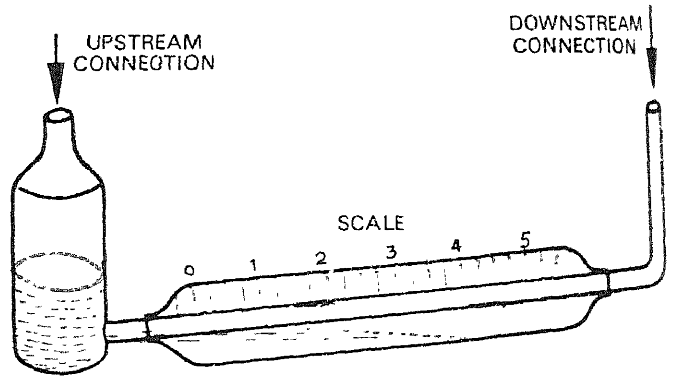
## Remember

**If you are not able to achieve at least 12% $CO_2$ reading by regulating the air supply without causing smoke, your burner may be defective.**

Ensure that the boiler is always operated at the air and fuel settings that have been determined. Check the settings for repeatibility, at least once every fortnight.

## Damper settings

In natural draft systems, excess air can be controlled by dampers placed before the chimney. Measurement of draft helps in setting the damper correctly for various loads. Simple inclined tube manometers can be used to measure the draft.



(Fig.5) —INCLINED TUBE MANOMETER

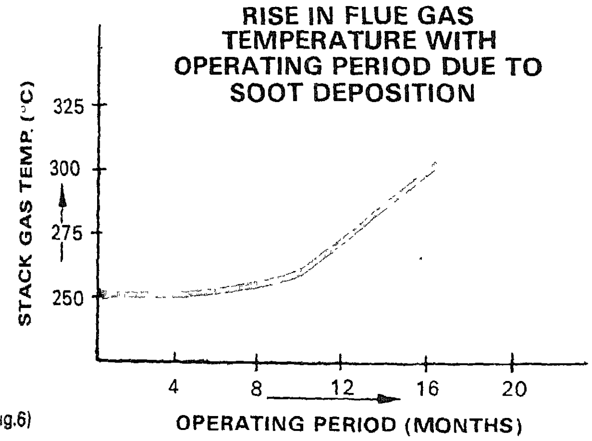
Remember, there is no precise relationship between the damper position and the amount of draft. Thus a half closed damper does not necessarily pass half the quantity of air. As the damper is closed gradually, the draft gauge may not show any significant reduction in draft up to a certain point.

By a trial using flue gas analysis to monitor excess air levels the correct draft for minimum excess air required for smokeless combustion, can be determined for various loads of the boiler. After calibrating the draft gauge for various loads, dampers should be operated at any load to obtain the predetermined optimum draft for that load.

## Gas side deposits

When conditions do not permit complete or total combustion of fuel oil, unburnt carbon particles, known as soot, are deposited on the inside of fire tubes in case of shell and packaged boilers and on the outer walls of water tubes in the case of water-tube boilers. Corrosion deposits are also found in boilers in the high temperature zones, such as the super heater, due to the melting of certain low melting point components of fuel-oil-ash. In the low temperature zones of the boiler like economiser, the air preheater and the induced draft fan, corrosion deposits due to the condensation of sulphur trioxide present in the flue gases can also occur.

These deposits slowly build up over a period of time, resulting in a higher flue gas temperature and hence greater heat loss. The fig. 6 shows the rise in flue gas temperature, over a period of time, due to soot deposition.

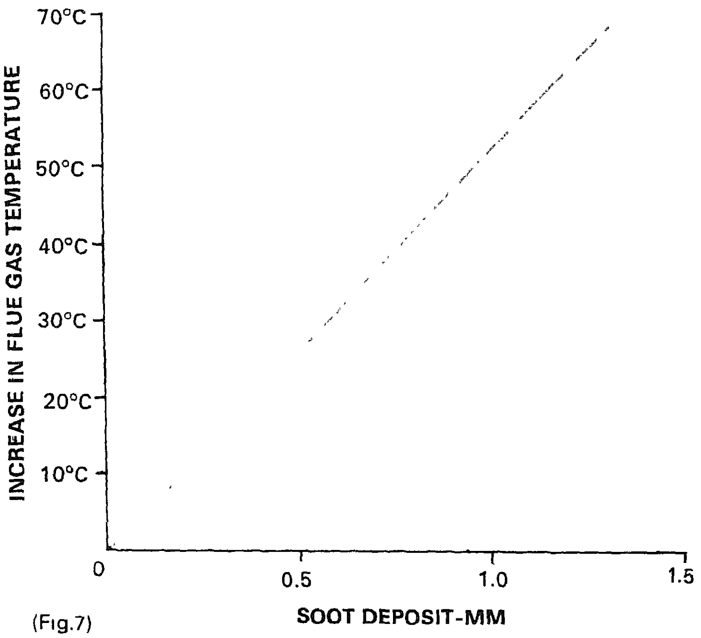


(Fig.6)

## Remember

**When flue gas temperature rises about 38°C above the normal, it is time for removing the soot deposits.** It is, therefore, recommended to install a dial type thermometer at the base of the chimney to monitor the exhaust flue gas temperature.

It is estimated that a coating of 3 mm thick soot on the heat transfer surface can cause an increase in fuel consumption as much as 2.5%. In large boilers, soot blowers are installed in the furnace section, superheater and in the air preheater/ economiser zone. Contact your boiler manufacturer for installing a soot blower in your boiler.



(Fig.7)

## Water side deposits and water softening

Sufficient care is usually devoted to keep the gas side free from accumulation of deposits that would interfere with heat transfer. However, in many low pressure boiler installations, adequate care is not taken to keep water side free from deposits, though many simple forms of modern water treatment equipment and facilities are available. **A 1mm thick scale (deposit) on the water side could increase fuel consumption by 5 to 8%.**

All the waters irrespective of their sources, contain impurities. These impurities are usually in soluble state with the water or at times in a state of suspension. The temperature of the water has a marked effect on solubility. Some impurities become less soluble as temperature rises and starts precipitating; either in the form of a non-adhering, soft sludge (which can be removed without difficulty by boiler blow down) or as a firmly adhering scale. This accumulation considerably reduces the rate of heat transfer and introduces the risk of overheating and failure of the affected surface. This becomes more serious as the boiler pressure and heat transfer rates increase to a point when temperature approaches more closely the upper safe value for the materials used.

The most important dissolved salts from the point of boiler feed, are those of calcium and magnesium. Their presence makes water hard and a deposit or scale is formed rapidly by the use of such water in boilers. Silica is also important, particularly in the case of high pressure boilers, as it forms a hard scale. Further, silica may be steam-volatile, creating problems with turbine blades. Bicarbonates, carbonates, hydroxides, chlorides, sulphates and nitrates of calcium, magnesium and other heavy metals may be present in water. The bicarbonates, carbonates and hydroxides of calcium and magnesium give rise to 'alkaline' or 'carbonate' hardness and the chlorides, sulphates and nitrates to 'non-alkaline' or 'non-carbonate' hardness

Treatment of raw water to prevent scale formation is called water softening. The chemical composition of water supplies vary greatly. There is, hence, no ideal treatment. Treatment has to be chosen based on a chemical analysis of the water, to find out how much of the various impurities and other chemical substances are present.

The hardness of water is expressed in different forms. A convenient form is milligrams of calcium carbonate per litre of water (mg/litre). Although the hardness may be due to soluble salts of calcium, magnesium, iron, manganese, aluminium or other heavy metals, the result is expressed as equivalent milligrams of calcium carbonate per litre of water.

The following methods are commonly used to soften water.

**A) Precipitation method:**

In this method, chemicals are added to precipitate calcium and magnesium as insoluble compounds, which are then separated by sedimentation and filtration. The lime-soda process is the oldest and most widely used method of precipitation softening. In this process, water is treated with hydrated lime (calcium hydroxide) and soda ash (sodium carbonate). Coagulants such as sodium aluminate, magnesium oxide or alum, are also added to the lime-soda mixture to improve precipitation. The theoretical quantity of chemicals required can be calculated from the following formulae:

Hydrated lime to be added in kg/1000 litres = 0.00074 × [carbonate hardness (as Ca $CO_3$) mg/litre + magnesium hardness (as Ca $CO_3$) mg/litre.]

Soda Ash to be added in kg/1000 litres = 0.0011 × (non-carbonate hardness (as Ca $CO_3$) mg/litre.

Sodium aluminate to be added in kg/1000 litres = 0.02 × (total hardness (as Ca $CO_3$) —up to a maximum of 200 mg/litre hardness.

Or 0.03 × total hardness (as Ca $CO_3$) in case of higher hardness levels.

The quantities above are for pure chemicals based on complete reaction. In actual practice, a small excess over the above theoretical amount is found necessary to obtain best results. In general, a 5% excess is recommended. Wherever necessary, the charge may be further adjusted, to obtain the desired results.

**b) Ion exchange method:**

If water containing calcium and magnesium salts in solution is passed through a bed of ion exchange material (i.e. synthetic or natural) calcium and magnesium ions are retained by the material and replaced by sodium so that the water leaving the mineral bed contains sodium salts instead of calcium and magnesium salts. In another method, partial deionisation to reduce dissolved solids is carried out by passing the water through a bed of ion exchange resins in hydrogen ion form, which converts carbonates and bicarbonates into carbonic acid and sulphates, nitrates and chlorides into their respective acids (the cations are retained by the resin itself). The water is subsequently aerated to remove carbon dioxide and is either neutralised with sodium hydroxide to produce zero hardness water of less dissolved solid content, or can be further treated by passing through a bed of anion exchange resin to remove all free acids. The latter treatment results in demineralized water containing as low as 5 mg/litre of total dissolved solids.

**c) Distillation method:**

Raw water is distilled in an evaporator, and the distillate, which is almost completely free from dissolved solids, is used. As the evaporator itself may be considered as a very low pressure boiler, the feed may, under certain conditions require softening. The distillation process is not generally required for low pressure boilers.

**d) Internal treatment:**

When water has low hardness, and comparatively small quantity is required to be treated, an external water treatment plant based on ion exchange or precipitation or distillation becomes impracticable and uneconomical. Under such conditions, internal treatment is applied. In this treatment, certain chemicals are administered directly to the water, entering the boiler which causes the hardness, producing salts to precipitate inside the boiler in the form of a smooth flowing sludge. Different waters require different chemicals. Sodium carbonate, sodium aluminate, sodium phosphate, tannin, starch and other compounds of vegetable or inorganic origin are used for this purpose. The sludge is removed during boiler blow down. This process is suitable for use particularly in low pressure boilers.

**Remember: Boiler water treatment involves more than just scale prevention. Important is the kind and control of chemical treatment, regulating the preheating and pretreating of make up and proper control of boiler blow down to prevent a buildup of solids and sludge in the drum. Supervision and control of this programme calls for a qualified operator. Prevention of feed water trouble usually costs far less than the repair of neglected equipment. Careful choice of water treatment plants can avoid many problems in future.**

## Boiler loading

The figure 8 gives the relationship between efficiency and loading of a boiler. It is important that one should load a boiler close to its normal economic rating and thereby achieve highest efficiency. However, this may not be possible in actual practice on account of the fluctuating loads on the process side. It is, therefore, necessary for you to determine the efficiency of the boiler at various load factors normally encountered. If you have a battery of boilers and their load characteristics are known, it would be possible for you to allocate the loads in such a manner that the total steam generation is at the highest efficiency.

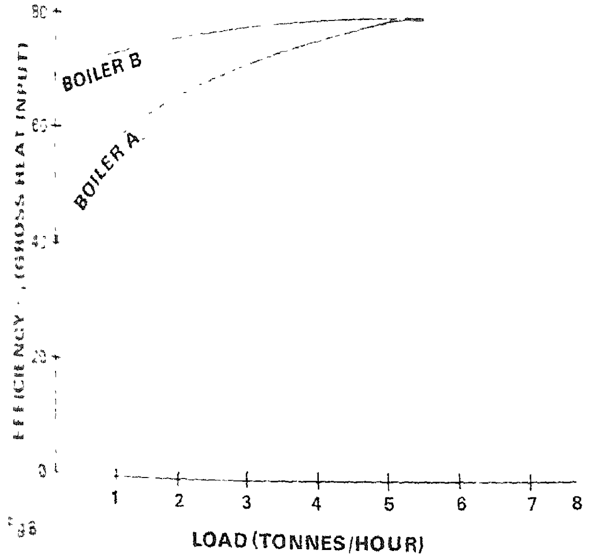


Fig 8

## Remember

**Boilers with a steep load characteristic should always be operated close to their normal economic rated loads.**

## Example

The boiler characteristic curve of two boilers, A and B, indicate that boiler A has a steep relationship between efficiency and load as against an almost constant efficiency at varying loads encountered in Boiler B. It will be apparent to the reader that the plant's total steam demand is 7 Tonnes/Hour. Boiler A should be loaded up to 5 Tonnes/Hour at which its efficiency is maximum and Boiler B should be used to meet the remaining steam demand of 2 Tonnes/Hour.

## Blow down

The concentration of total dissolved solids (TDS) in boiler water can be chemically determined and is reported as parts per million (PPM). Different boilers can tolerate different levels of concentration of dissolved solids in the boiler drum.

To maintain boiler water concentrations within the specified upper limit of boiler water TDS, blow down is resorted to. The following formula gives the quantity of blow down required:

$$\text{blow down }(\%) = \frac{\text{TDS in feed water}}{\text{Maximum permissible TDS in boiler water}} \times (\%\text{ make up water})$$

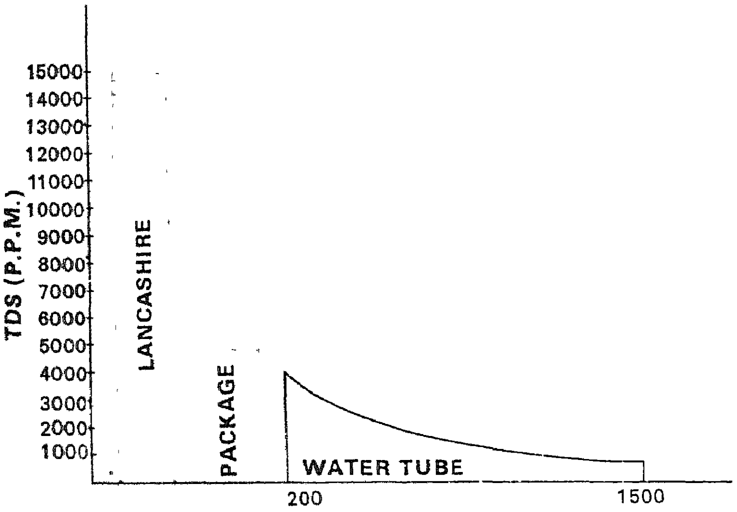
**Example**: If maximum permissible limit of TDS in a boiler is about 3500 PPM and percentage make up water is 40 and if TDS in feed water is 350 PPM then the percentage blow down

$$= \frac{350}{3500} \times 40 = 4\%$$

If boiler evaporation rate is 5500 kg/hr, then required blow down rate:

$$= \frac{5500 \times 4}{100} = 220 \text{ kg/hr.}$$

Blow down maybe continuous or intermittent. In continuous blow down, there is a steady and constant despatch of a small stream of concentrated boiler water from the drum. At today's fuel prices, it is worthwhile to consider heat recovery from blow down. The figure 10 gives a system by which heat can be recovered from boiler blow down.



(Fig.9)

## Recovery of condensate

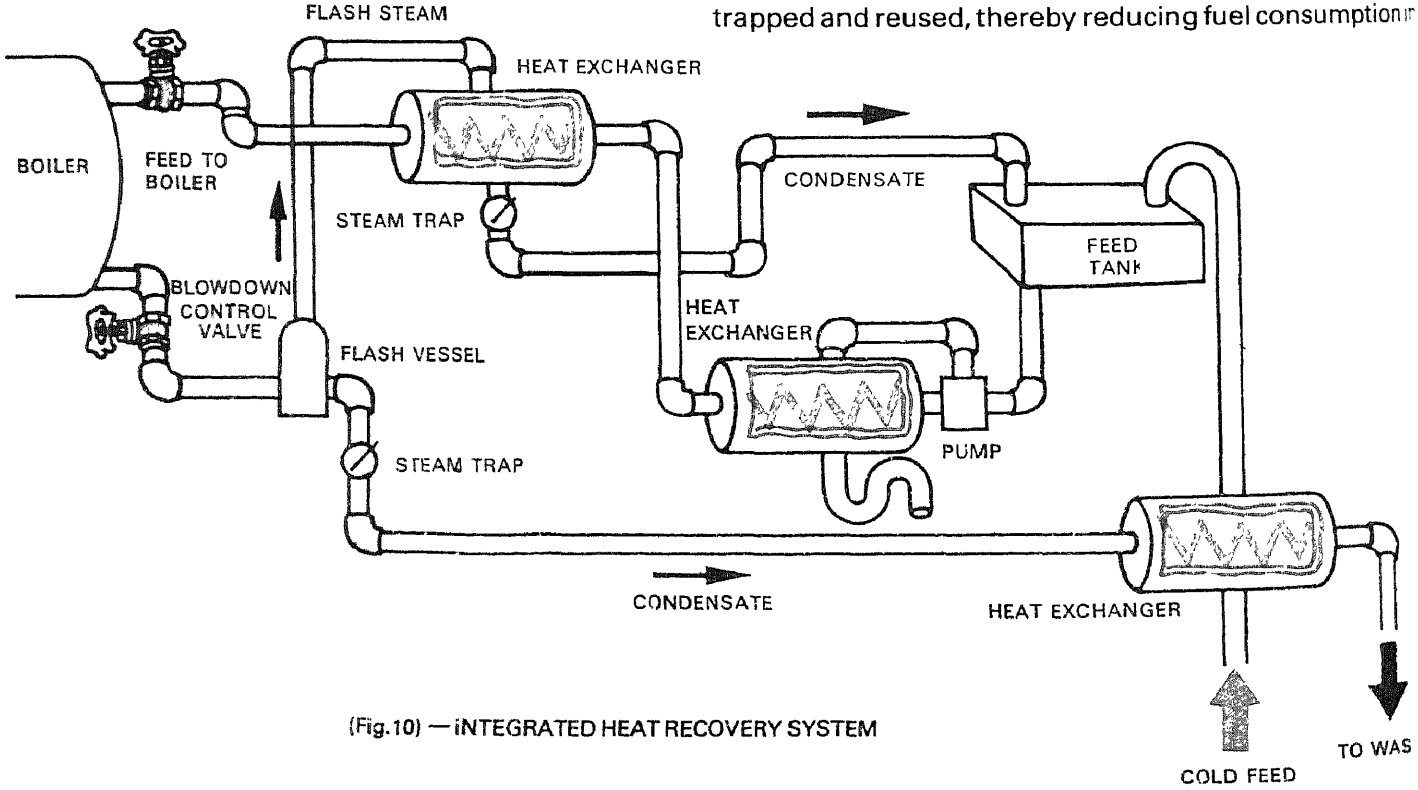
Clean condensate from process departments is a valuable source of heat which can be used in the boiler house as feed water. Apart from reducing fuel requirements in the boiler by raising the boiler feed water temperature, this also reduces water treatment costs, since condensate is like distilled water, and needs no water treatment. Hence, before exploring the use of an economiser, it is advisable t check whether all the condensate that can be economica recovered, is being returned to the boiler house.

## Remember

**For every 6°C rise in boiler feed water temperature throug condensate return, there is 1% saving in fuel.**

## Flue gas heat recovery

Waste heat which escapes through the chimney can be trapped and reused, thereby reducing fuel consumption i



(Fig.10) — INTEGRATED HEAT RECOVERY SYSTEM boiler. In an economiser, the waste heat is used to increase the boiler feed water temperature. On the other hand, in an air pre-heater, the waste heat is used to heat combustion air. In both the cases, there is a corresponding reduction in the fuel requirements of the boiler.

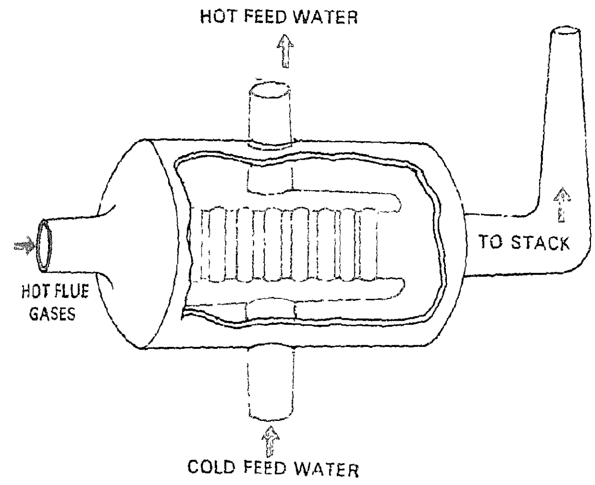


Fig 11) **ECONOMISER**

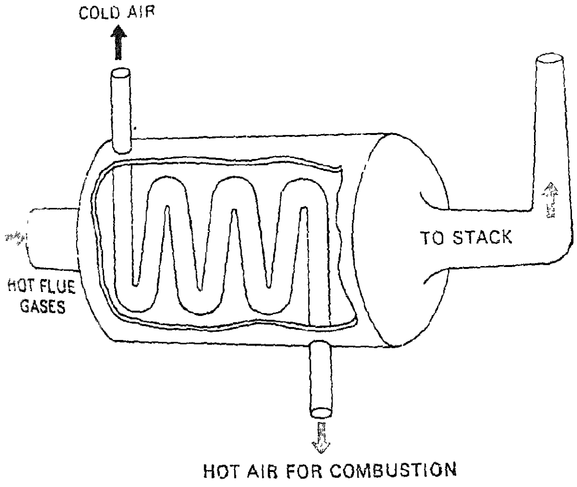


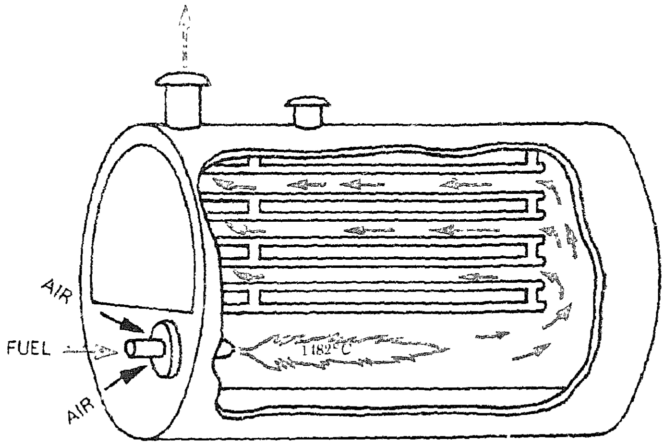
Fig 12) **AIR PREHEATER**

## Remember

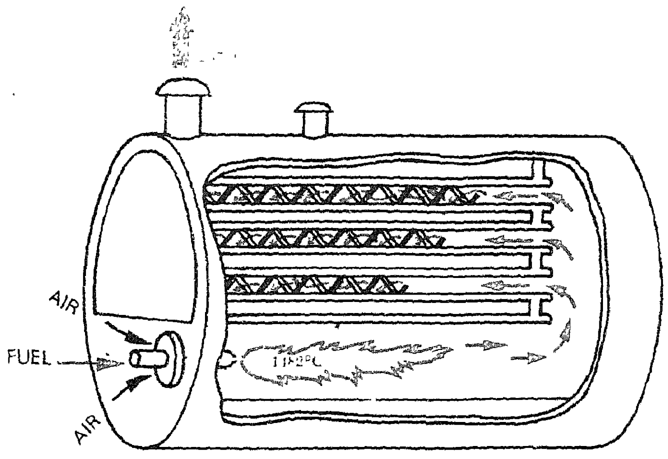
**For every 22°C reduction in flue gas temperature by passing through an economiser or a pre-heater, there is 1% saving of fuel in the boiler. In other words, for every 6°C rise in feed water temperature through an economiser, or 20°C rise in combustion air temperature through an air pre-heater, there is 1% saving of fuel.**

## Turbulators

Turbulators are a set of baffles arranged at different angles which are installed in the secondary passes of an oil fired



(Fig. 13) HOTTEST GAS FLOWS THRU TOP ROWS OF TUBES ONLY.



GAS FLOW EQUALIZED THRU ALL TUBES

(Fig. 14) TWO PASS FIRETUBE BOILERS WITH AND WITHOUT TURBULATORS.

firetube boiler to increase flame turbulence and thereby increase convective heat transfer to the surrounding boiler water.

This device also helps in balancing the flue gas flow through the fire-tubes to achieve more effective utilization of existing heat transfer surfaces. The figures 13 and 14 depict a two pass Scotch Marine fire-tube boiler with and without turbulators. The improvement in boiler performance will be indicated by the decrease in stack temperature and the corresponding increase in steam generation.

## Boiler feed tank

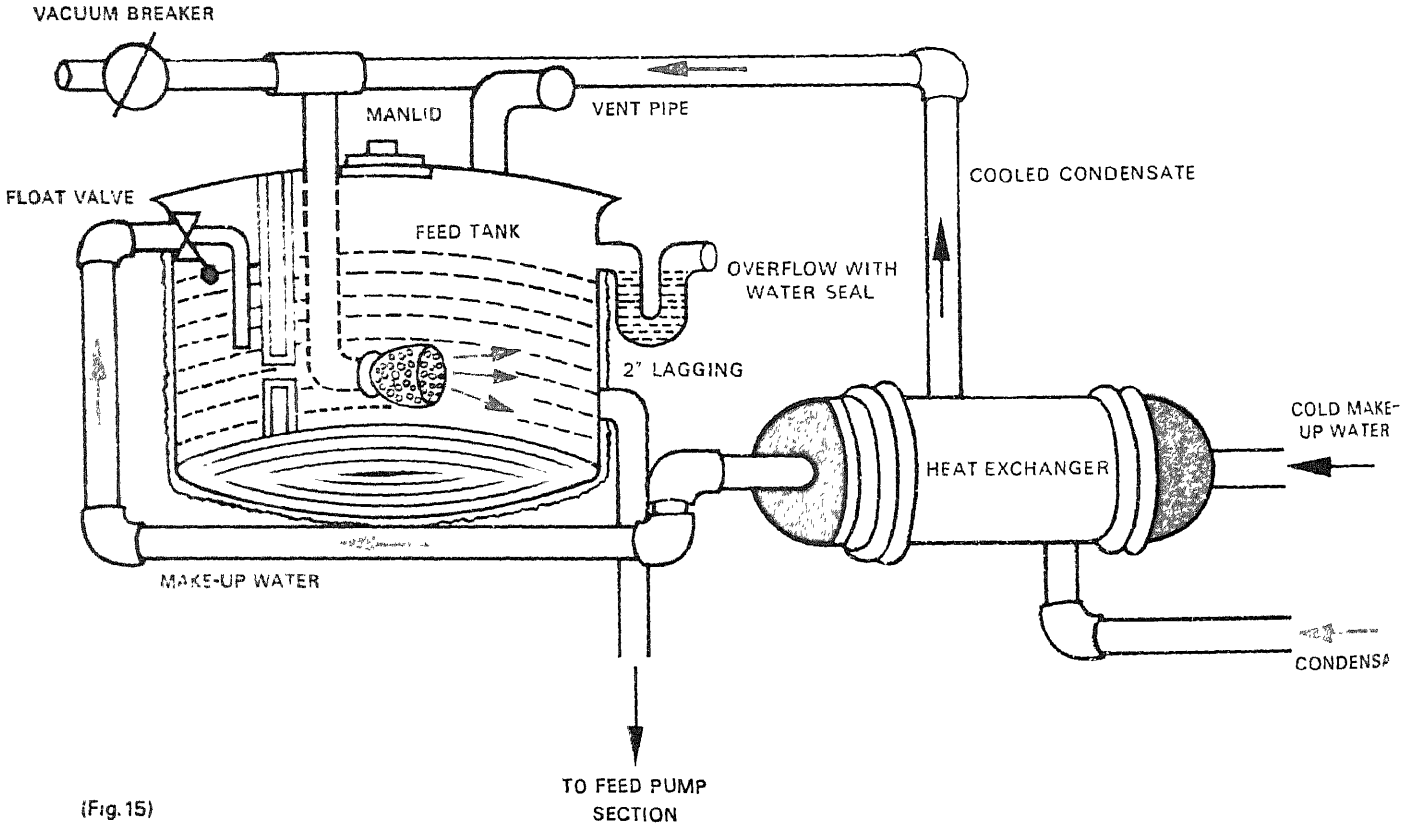
It is desirable to provide a feed water tank with a capacity, at least equal to one hour's maximum boiler evaporation. The feed water should be maintained at as high a temperature as possible by recovering heat from all the sources of waste heat such as condensate return, heat from boiler blow down, heat from steam pre-heater condensate or exhaust heat where steam pumps are used.

To avoid cavitation at the pump, it is advisable to provide the feed tank at a sufficient height above the pump level. The following table gives recommended heights where steam feed water pumps are used.

| **Feed water temperature** | **Required height** |
|---|---|
| 86°C | 1.5 metres |
| 90°C | 2.1 metres |
| 95°C | 3.5 metres |
| 100°C | 5.2 metres |

Slightly lower heads can be used for centrifugal pumps.

The feed tank should be provided with a tight fitting lid preferably bolted on, and should have an adequately sized vent pipe and over flow. The condensate return line normally carries some flash steam. If it is connected with the top of the tank, this steam will easily escape through the vent pipe. The return line should therefore be carried below the water level so that much of the flash can be condensed. A check valve should be fitted to act as a vacuum breaker to prevent the water from the tank being sucked back into the condensate return line. Where large quantity of flash is



(Fig. 15)

unavoidable at the feed tank, and a reasonable amount of cold make-up water is required, a heat exchanger may be used to condense the flash steam and cool the condensate using either cold make up or process water as the cooling medium.

A supply of water should be connected to the tank to make-up for any difference between the amount of condensate returned and boiler evaporation.

This make-up supply should be automatically controlled by means of a float operated valve.

The level of the float should be so adjusted that cold water is admitted only after full allowance has been made to receive all possible hot water.

The most suitable level can only be decided with a knowledge of the operating conditions in the individual installation. If an ordinary ball valve is used to control the make-up, it may not last long in the hot turbulent conditions that exist in the tank. It can be fitted in a small separate tank to overcome this trouble.

The feed tank should be well lagged to conserve as much heat as possible. A water meter fitted on the suction line of the feed pump gives a very useful indication of total boiler evaporation.

It is important to remember that for approximately every 6°C rise in feed water temperature, the boiler will require 1% less fuel. A thermometer on the feed tank or pump suction line can be of considerable use in keeping a check on feed temperature.

## Selection of boiler

Is the boiler really necessary?
What should be its specifications?
What type of boiler should be selected?
These are some vital questions which have to be carefully answered before a new boiler is purchased.

The first step is to examine the need for the boiler. The pattern of steam demand of the plant should be carefully assessed. In many instances, careful production planning and scheduling can help in minimising the steam demand peaks, and hence the need for a new boiler to meet these peaks. A vigorous steam economy drive also often results in avoiding the need for a new boiler. Having determined the pattern of steam demand in the plant, the required additional boiler capacity can easily be worked out. While planning for a new boiler, future expansion and steam demand should be kept in mind for fixing the boiler capacity. It should be remembered that too high a capacity may necessitate the operation of the boiler uneconomically at low loads.

The next step is to determine the steam pressure required. The operating pressure of the boiler should be slightly higher (around 1 kg/cm$^2$, in small and medium plants) than the maximum pressure of steam required by any process for which supply is to be made by the boiler. The boiler should be capable of generating steam at least at this pressure or at a higher pressure.

Once the required steam pressure, temperature and capacity are known, suitable selection can be made from the boiler ranges available with manufacturers. It should, however, be remembered that there are fairly wide variations in the efficiency of generation among different types of boilers.

A study of over 2500 boilers of various makes and sizes by PCRA in Indian Industry has indicated the performance of boilers commonly used as shown in figure 16.

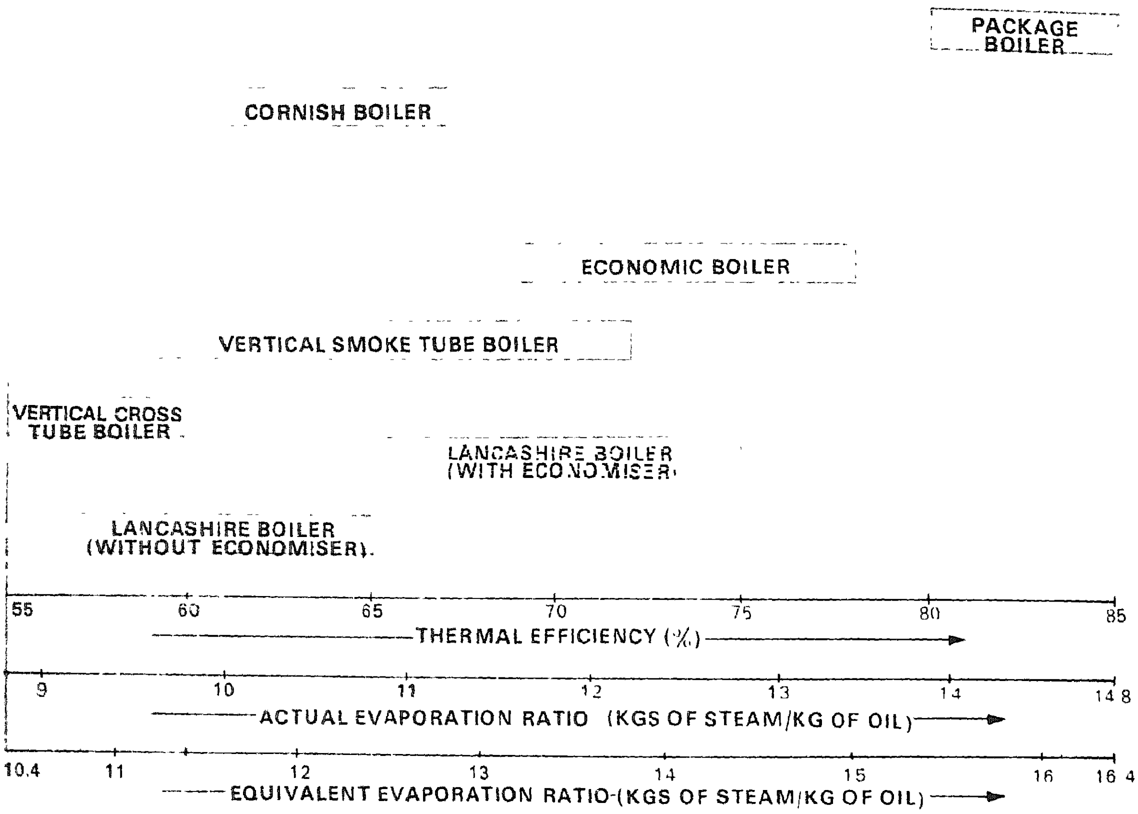
It may be noted that package boilers have significantly higher thermal efficiencies. Inspite of lower efficiencies, Lancashire and vertical boilers are very common in India. They are more rugged and can tolerate poor quality feed water as well as poor operation with greater safety than other boilers. With increasing emphasis on efficiency of generation along with improvements in operators' skills and quality of water treatment, the era of such boilers is slowly coming to an end.

The steam generating capacity of a boiler is often specified in terms of Equivalent Evaporation (Kg of steam/hour from and at 100°C). Equivalent Evaporation expresses the heat capacity of the boiler in terms of the heat required to evaporate the specified quantity of feed water from a temperature of 100°C to dry saturated steam at 100°C (i.e. 540 Kcal/kg). In actual boilers, feed water temperatures may be different and the generated steam is at a higher temperature. Actual Evaporation hence, tends to the lower than Equivalent Evaporation.

$$\text{Equivalent Evaporation} = \frac{\text{Actual Evaporation} \times (H - h)}{540} \text{ kg/hr}$$

where H = total heat in generated steam (Kcal/kg)
and h = heat content in feed water (Kcal/kg).

If the pressure and temperature of steam as well as the temperature of feed water is known, values of H and h can be obtained from steam tables.



(Fig. 16) — PERFORMANCE RANGE OF BOILERS

**Example:** If a boiler generates 4.0 tonnes of steam/hr at a pressure of 7 kg/cm² and dryness fraction of 0.9 with a feed water temperature of 30°C—

$H = 612$ Kcal/kg

$h = 30$ Kcal/kg

$$\text{Equivalent Evaporation} = \frac{4.0 \times (612 - 30)}{540}$$

$$= 4.3 \text{ T/hr.}$$

Manufacturers may be asked to specify guaranteed levels of Equivalent Evaporation as well as efficiency.

$$\text{Efficiency} = \frac{\text{Actual Evaporation} \times (\text{H-h})}{\text{Fuel consumed per hour} \times \text{Gross caloric value of fuel}}$$

After installing a boiler, a boiler trial should be conduct Actual Evaporation may be measured by means of either a freshly calibrated steam flow meter, or by a hot water mete fitted on the feed water line. If a water meter is used, care should be taken to equalise the water level in the boiler drum before taking water consumption readings. If flow meters are not available, water should be taken from a separate calibrated tank to which the condensate is not returned. Fuel consumption during the trial period is usua measured by dip readings of the service tank or by using a correctly calibrated fuel flow meter.

REFERENCE :

1. The Efficient Use of Steam — Oliver Lyle, HMSO, London.
2. Boilers — Types, Characteristics & Functions — Carl D. Shields, McGraw-Hill Book Co.

**This booklet is one of a series on fuel oil conservation, others in the series are listed below:**

1) Storage, handling and preparation of fuel oil.
2) Combustion of fuel oils & Burners—operation and maintenance.
3) Efficient generation of steam.
4) Efficient utilisation of steam.
5) Refractories.
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# 4

# Efficient utilisation of steam

PCRA

# Introduction

Nearly 2 out of every 3 litres of fuel oil used in industry is for generating steam in industrial boilers. The very purpose of generating steam at the highest thermal efficiency is lost if the steam is subsequently wasted through improper distribution or utilisation.

Saving steam will have a multi-directional impact on the overall conservation programme. Foremost, it would result in considerable savings of furnace oil in the boilers than the same effort on improving boiler efficiency. The peak demand for steam could drop down to a level within the operating capacity of the boiler house, thereby avoiding fuel wastage through overloading or the need for additional boiler(s). Overall production time too could be reduced, thus increasing the output of the steam consuming equipment. Thus, the productivity of the overall steam-consuming manufacturing operation could be improved.

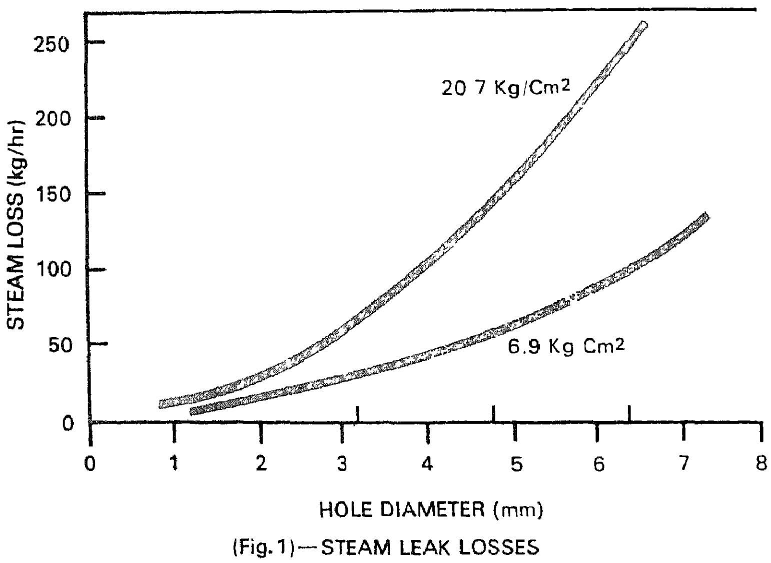
In this booklet, such key result measures are covered as can be readily followed and implemented to improve steam distribution and utilisation in industries.

# Key result areas for efficient steam utilisation

1) Avoiding steam leakages.
2) Providing dry steam for process.
3) Utilising steam at the lowest practicable pressure for process.
4) Insulation of steam pipelines and hot process equipments.
5) Proper utilisation of directly injected steam.
6) Proper air venting.
7) Minimising barriers to heat transfer.
8) Condensate recovery.
9) Flash steam recovery.
10) Proper selection and maintenance of steam traps.
11) Proper sizing of steam and condensate pipelines.
12) Reducing the work to be done by steam.

## 1. Avoiding steam leakages

Steam leakage is a visible indicator of waste and must be avoided. It has been estimated that a 3 mm diameter hole on a pipeline carrying 7 kg/cm² steam would waste 32.65 KL of fuel oil per year. Steam leaks on high pressure mains are prohibitively costlier than on low pressure mains.



(Fig. 1)—STEAM LEAK LOSSES

Any steam leakage must be quickly attended to. In fact, the plant should consider a regular surveillance programme for identifying leaks at pipelines, valves, flanges and joints as soon as they occur. Indeed, by plugging all leakages, one may be surprised at the extent of fuel savings, which may reach upto 5% of the steam consumption in a small or medium scale industry or even higher in installations having several process departments.

To avoid leaks it may be worthwhile considering replacement of the flanged joints which are rarely opened in old plants by welded joints. These days, technology is available to plug online steam leaks. Even continuous process industries can take advantage of this.

## 2. Providing dry steam for process

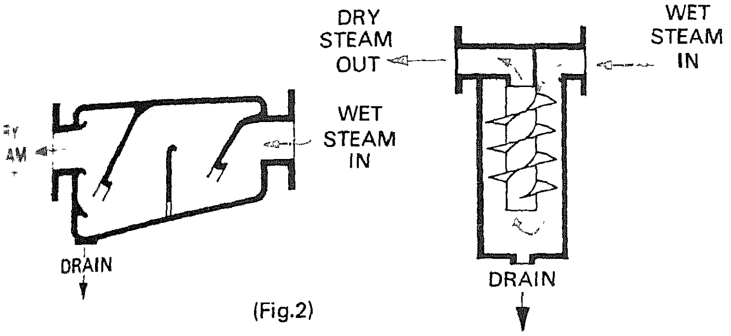
The best steam for industrial process heating is dry saturated steam—neither wet nor superheated. If steam is wet, the trapped moisture particles reduce the total heat in the steam (since they carry no latent heat), and increase the resistant film of water on the heat transfer surfaces, thereby slowing down the rate of heat transfer. Such moisture also overloads the traps and other condensate handling equipment. On the other hand, superheated steam is not so practical or desirable for process heating because its temperature in the plant cannot be effectively controlled (unlike saturated steam whose temperature depends only on the pressure), and also because it gives up its heat at a rate slower than the condensation heat transfer of saturated steam.

It must be remembered that a boiler without a superheater cannot deliver perfectly dry saturated steam. At best, it can deliver only 95% dry steam. The dryness fraction of steam depends on various factors, such as the level of water in the boiler drum, the effect of peak loads, the surging within the boiler, the pressure on the water surface in the boiler and the solids content in the boiler water. Any one of these factors or combination of them can cause droplets of water to be a part of the steam. Indeed, even as simple a thing as improper boiler water treatment can become a cause for wet steam.

As steam flows through the pipelines, it undergoes progressive condensation due to the loss of heat to the colder surroundings. The extent of the condensation depends on the effectiveness of the lagging. For example, with poor lagging the steam can become excessively wet.

Since dry saturated steam is required for process equipment due attention must be paid to the boiler operation and lagging of the pipelines. A steam separator may be installed on the steam main as well as on the branch lines to reduce wetness steam and improve the quality of the steam going to the use units.

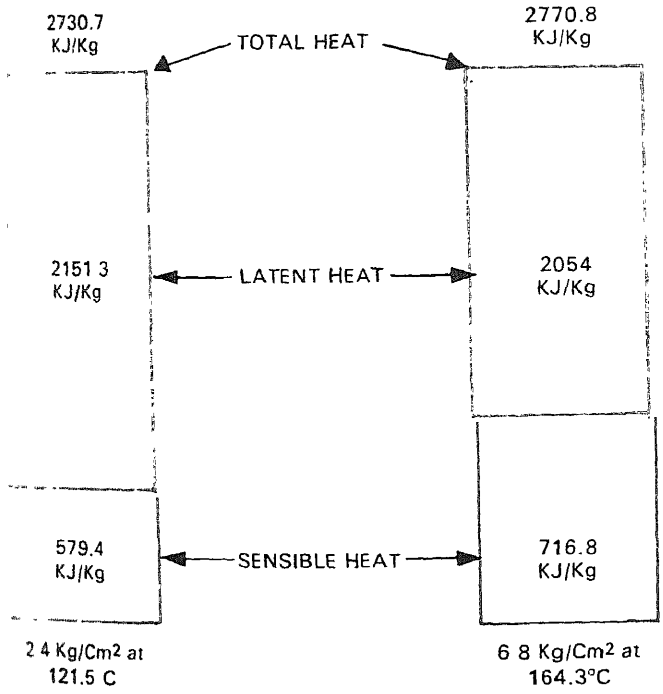
There are two types of steam separators commonly used in industries, as shown in Fig. 2.



(Fig.2)

In all types of steam separators, a change in the direction of the steam flow results in the trapped water particles being dropped and delivered to a point where they can be drained away as condensate through a steam trap.

The simple baffle type separator provides the moisture particle an obstacle on which they impinge and fall to the bottom of the unit thereby allowing only dry steam to pass on further.



LATENT HEAT OF STEAM
AT 2.2 Kg/Cm2 is 2.7% MORE
THAN AT 6.8 Kg/Cm2

Fig.3) – COMPARISON OF LATENT AND SENSIBLE HEAT TO THE TOTAL HEAT AT TWO DIFFERENT PRESSURES OF STEAM

## 3. Utilising steam at the lowest practicable pressure for process

A study of the steam tables would indicate that the latent heat in steam reduces as the steam pressure increases.

It is only the latent heat of steam which takes part in the heating process when applied to an indirect heating system. Thus, it is important that its value be kept as high as possible. This can only be achieved if we go in for lower steam pressures. As a guide, the steam should always be generated and distributed at the highest possible pressure but utilised at as low a pressure as possible since it then has higher latent heat. However, it may also be seen from the steam tables that the lower the steam pressure, the lower will be its temperature. Since temperature is the driving force for the transfer of heat at lower steam pressures, the rate of heat transfer will be slower and the processing time greater. In equipment where fixed losses are high (e.g. big drying cylinders), there may even be an increase in steam consumption at lower pressures due to increased processing time. There are, however, several equipment in certain industries where one can profitably go in for lower pressures and realise economy in steam consumption without materially affecting production time.

Therefore, there is a limit to the reduction of steam pressure. Depending on the equipment design, the lowest possible steam pressure with which the equipment can work, should be selected without sacrificing either on production time or on steam consumption.

## 4. Insulation of steam pipelines and hot process equipment

Bare steam pipelines, flanges and hot process equipment give up heat to the atmosphere by radiation. Insulation seeks to reduce these heat losses.

It has been estimated that a bare steam pipe, 150mm in dia and 100 meters in length, carrying saturated steam at 8 kg/cm$^2$, could waste 25KL furnace oil in one year.

In case, the pipelines are already lagged, it pays to periodically review the effectiveness of the insulation. The booklet on 'Thermal Insulation' in this series provides detailed information on the types of insulation available, the determination of the optimum thickness and the method of applying insulation.
(For details, refer within this booklet).

## 5. Proper utilisation of directly injected steam

The heating of a liquid by direct injection of steam is often desirable. The equipment required is relatively simple, cheap and easy to maintain. No condensate recovery system is necessary. The heating is quick, and the sensible heat of the steam is also used up along with the latent heat, making the process thermally efficient. In particular processes where a certain amount of agitation is required, which can be created by blowing steam into the liquid—direct steam injection is applied. If, however, the dilution of the tank contents and agitation are not acceptable in the process, indirect steam heating is the only answer.

In a good number of plants, where water or process liquor is heated by direct steam injection, one can see the liquid in the tank boiling away, creating clouds of vapour.

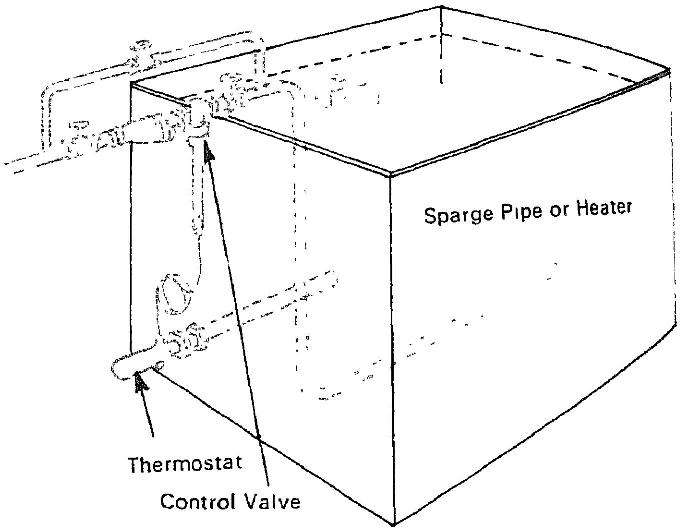
This is a waste of steam. Besides, it creates unpleasant working conditions.

Ideally, the injected steam should be condensed completely as the bubbles rise through the liquid. This is possible only if the inlet steam pressures are kept very low—around 0.5kg/cm$^2$—and certainly not over 1 kg/cm$^2$. If pressures are high, the velocity of the steam bubbles will also be high and they will not get sufficient time to condense before they reach the surface. Fig. 4 shows a recommended arrangement for direct injection of steam.

A large number of small diameter holes (2 to 5 mm), facing downwards, should be drilled on the sparge pipe. That way, the initial velocity of the bubbles is dissipated in the depths of the liquid.

Many processes call for the use of open vats of hot liquor. To allow, the temperature of the contents of such a vat to increase beyond required levels, for example upto 82°C, when 66°C is all that is needed, is to wastefully use as much as one-third of the total steam used in the process. If steam is used for 24 hours/day and seven days a week, the excess steam utilisation represents a fuel waste of approximately 90KL of oil a year. In such a situation, an automatic temperature controller, as illustrated in Fig. 4, should be used to reduce and control the heat demand.

A thermostatic control of steam admitted is also desirable, to avoid overheating of the liquor and wastage of steam. If however, the liquid must be kept boiling, it would be difficult to regulate the injection of steam, since the temperature of the liquid will not rise if excessive steam is admitted. If possible, such tanks should be provided with a lid and a vent. The escape of steam through the vent, visible to the operator, can then be used to control steam admission.



(Fig.4) — RECOMMENDED ARRANGEMENT FOR DIRECT REJECTION OF STEAM

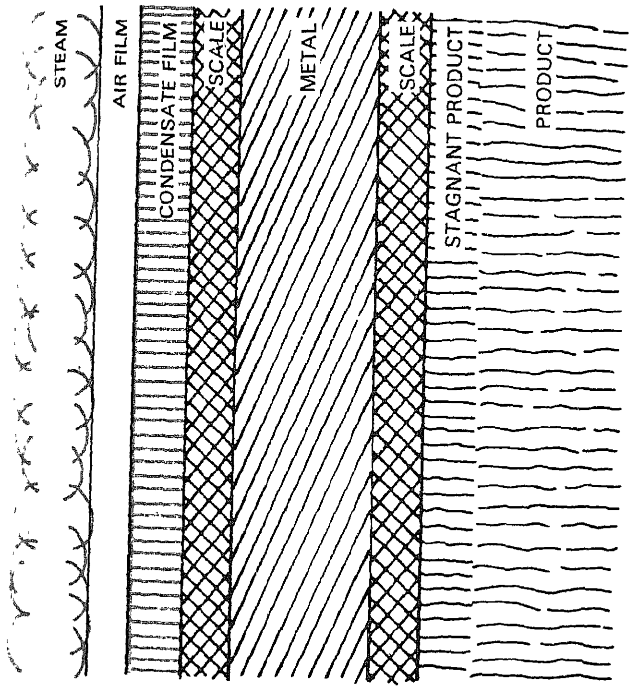
Steam in the pipe downstream of the controller tends to condense, forming a partial vacuum at the time of steam supply shut-off either by the temperature controller or due to the boiler shut-downs. As a result, liquor will be sucked back into the pipe system. This is bound to adversely affect not only the pipes, but may also harm the temperature controller, particularly if the liquor being heated is of corrosive nature and has suspended particles. Thus, some provision should be made to release the vacuum. It is a common practice to provide a check valve in reverse as shown in (Fig. 4).

## 6. Proper air venting

A 0.25mm thick air film offers the same resistance to heat transfer as a 330 mm thick copper wall. The presence of air inside the process equipment will reduce the partial pressure of steam in the steam-air mixture, thus dropping the overall temperature of the steam air mixture, which is the heating media. It is, however, impossible to avoid the entry of air into steam system that is working intermittently. If the steam condenses during the shut downs, air tends to be sucked in due to the partial vacuum created. Air is also pushed into the process equipment from the steam mains at the time of start up. The situation can be improved by installing properly sized air vents at appropriate positions in the pipelines and the jipment. The air vent should be so positioned that the pped air is pumped out of the equipment as quickly as ssible. The air vent should be positioned at the stagnant rner, remote from the steam inlet point. If steam inlet is low wn, the air vents should necessarily be placed at the top and it at the bottom. This will ensure that the incoming steam ill push out the entire trapped air in the equipment towards e air vents. Fig. 6 shows the desirable locations of air vents two typical applications.

nd operated cocks are widely used to remove air from eam installations, but they are often abused. If the start-up is uggish, the operator tends to open the vent, which he then uts either too early or too late.

OBSTACLES IN EFFECTIVE HEAT TRANSFER



(Fig.5)

Once the plant is running, the vent cock is probably left untouched, until output drops significantly, drawing the operator's attention to the open air vent. Where an inverted bucket or thermostatic trap is used to drain out the condensate, there may be no need to make the provision for a separate air vent, since these traps can handle and remove air and the condensate simultaneously.

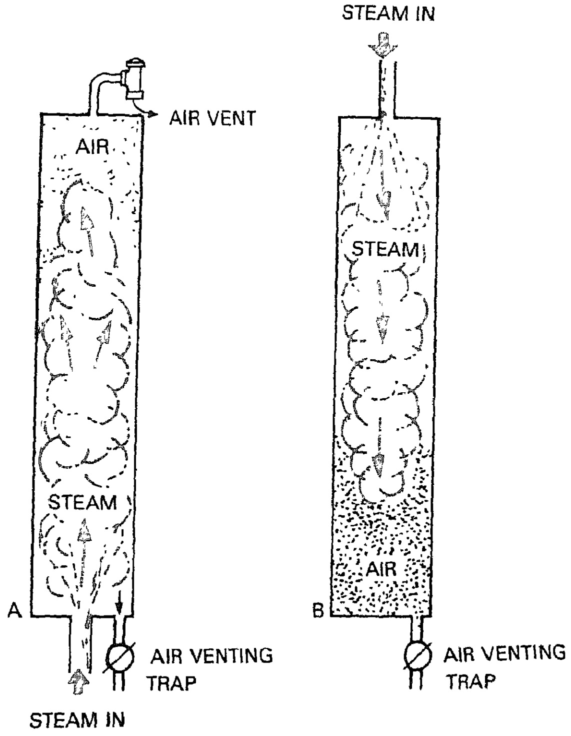
Automatic air vents are also available but they are relatively expensive and should be carefully maintained. The best automatic air vents are the balanced pressure or the liquid expansion types. The former are lighter, cheaper and have a quicker response, whereas the latter are more robust.

## 7. Minimising barriers to heat transfer

Heat is transferred from the steam to the material being heated in two ways:

a) By direct contact when steam is directly injected into the material in the chamber.

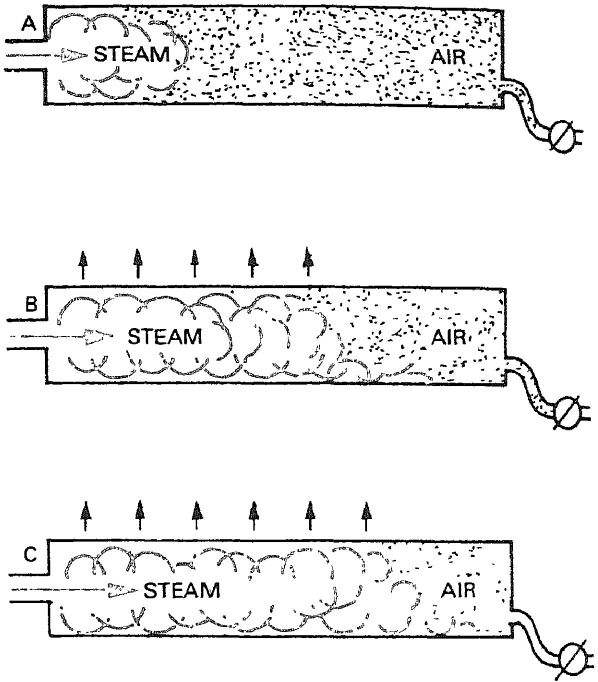
b) Through an intermediate heating surface which acts as a barrier between the steam and the material being heated.



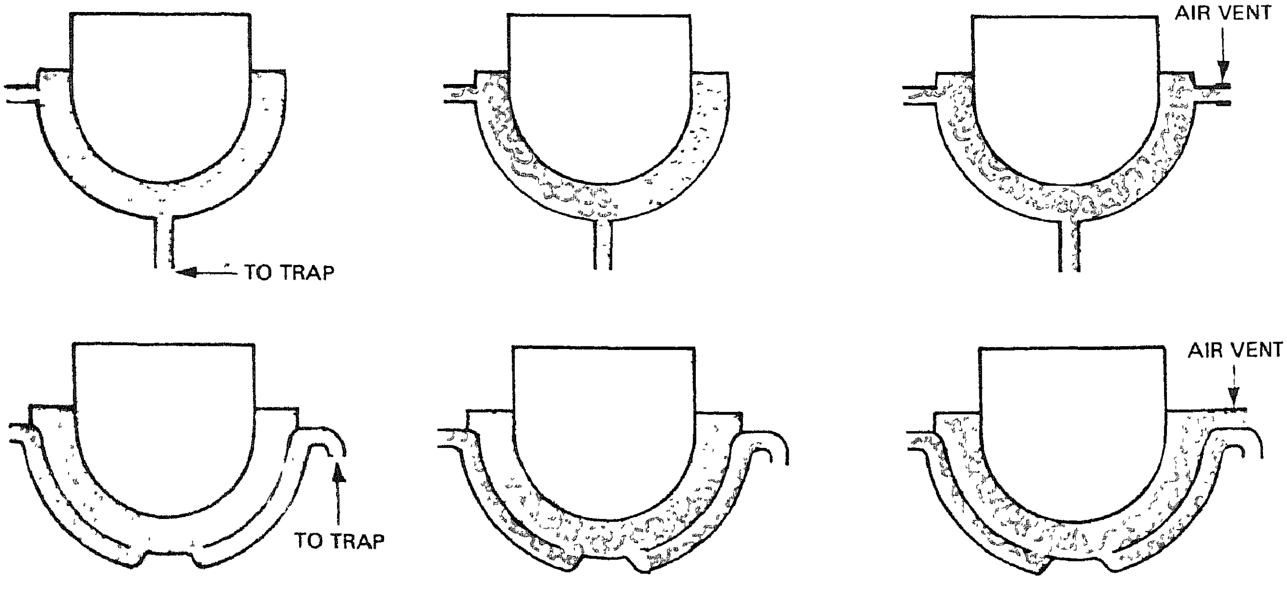
(Fig.6)—POSITIONING OF AIR VENT

The direct method has been discussed earlier. In the second method, that of indirect heating, a temperature difference is required to overcome the resistance of the barrier between the steam and the material. However, it is not just the thermal conductivity of the barrier which is an important factor. Alongside the heat transfer barrier is an air film as well as scaling on the steam side, and scaling as well as a stagnation product film on the product side. Fig. 5 illustrates the barriers which are formed that impede the flow of heat from steam to the material. It has been estimated that air is 1500 times more resistant to heat transfer than steel and 13,000 times more resistant than copper. Thus, an air film of 0.025mm thickness offers the same resistance to heat transfer as a 330mm thick copper wall. Air is probably the best heat insulator ever known. It is also the most likely material to be trapped in all steam supplies, because when steam condenses, air always tries to take its place on account of the partial vacuum created. Air is also carried into the steam space by incoming steam during start-ups. It is, therefore, essential that the equipment should be so designed that the trapped air is pumped out automatically at the very beginning.

Adequate air venting provision should be made to purge out air as quickly as possible from the equipment, making heat transfer more efficient. Fig. 6 gives the positioning of the air vent on steam mains. The location of the air vent in a steam cylinder is given in Fig. 7. Also, a typical air vent insulation for a jacketted vessel is indicated in Fig. 8.



(Fig.7) — BEHAVIOUR OF TRAPPED AIR



(Fig.8) — AIR VENTING OF STEAM JACKETED BOILING PANS

Now a word about removal of the condensate film. It is not possible to remove the condensate film for the simple reason that steam, when it comes into contact with the surface to be heated, gives up its latent heat and condenses, forming the insulating film we are seeking to reduce. When it enters the steam space, the water it carries is deposited on the heated surface, increasing the insulating water film, but contributing no actual heat transfer process. To prevent water droplets from entering the equipment, it may be necessary to use a steam separator, as already discussed in (2.)

## 8. Condensate recovery

The steam condenses after giving off its latent heat in the heating coil or the jacket of the process equipment. A sizeable portion (about 25%) of the total heat in the steam leaves the process equipment as hot water. If this water is returned to the boiler house, it will reduce the fuel requirements of the boiler. For every 6°C rise in the feed water temperature, there will be approximately 1% saving of fuel in the boiler. However, in most cases, the boiler water has to be chemically treated to prevent or reduce scale formation, whereas the condensate is almost entirely pure water which needs no treatment. With a good percentage of the condensate returning to the boiler house, the expenses involved for water treatment will be reduced by an appreciable amount.

In some cases, the return of the entire condensate can make the feed too hot to handle. The extra-high temperature feed water may lead to the cavitation of the feed pump, which can be overcome by arranging the feed tank at a certain height, so that it provides a positive head at the suction point of the pump. The necessary head will depend upon the temperature of the water and the type of the pump. Table I gives the height required for the feed temperature for most of the pumps. This can, in some cases, be reduced, in consultation with the pump manufacturers.

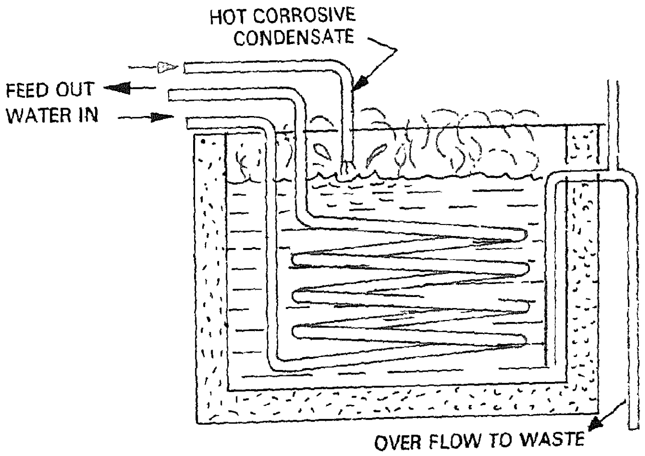
**Table I**

| **Temperature of water (°C)** | **Height required (Metres)** |
|---|---|
| 88 | 1.6 |
| 93 | 3.2 |
| 99 | 4.8 |
| 100 | 5.5 |

In some cases, where the boiler plant incorporates an economiser, the recycling of the entire condensate may lead to the feed water inlet temperature exceeding the limit that can be safely handled by the economiser. In such cases, some heat can often be taken out of the condensate in the form of flash steam and efficiently utilised in other processes.

There may be some exceptions, particularly in very large plants. Here, the investment of such a return system is very high while the heat that can be recovered is very small. In such cases, the condensate is not fully recycled to be used as boiler feed. The real justification and working of cost-benefit analysis depends on the actual site conditions. But in most cases, it is possible to make use of the heat in the condensate, either using it directly as process hot water or by recovering the heat through a heat exchanger.

Another reason for not returning the condensate may be the fact of its being contaminated in certain processes, such as in the plating process, where the vats are heated by steam coils, and a small leak in the coil allows acid to pass into condensate system. To prevent this from being recycled into the boiler, the condensate from these vats is made use of in the hot tanks.



(Fig.9) — UTILISING CORROSIVE CONDENSATE

Alternatively, heat can be usefully recovered from contaminated condensate by passing it through a heat exchanger. Where the occurence of contamination is not frequent, but to protect the plant against such incidents, it is best to use conductivity meters on the condensate line.

Pumping of the condensate from the condensate collection tank to the main feed water tank can then be automatically stopped as soon as the meter detects contamination. In many instances, such as in Oil Refineries, where there are possibilities of oil contamination, the condensate is passed through a 'Trace Detector' which can detect the contamination and give adequate warning. Such instrumentation is usually expensive and is only justifiable where large quantities of condensate are being recovered from sources of possible contamination.

## 9. Flash steam recovery

Flash steam is produced when condensate at a high pressure is released to a lower pressure and can be used for low pressure heating.

The flash steam quantity can be calculated by the following mathematical formula with the help of a steam table:

$$\text{Flash steam available } \% = \frac{S_1 - S_2}{L_2}$$

where: $S_1$ is the sensible heat of higher pressure condensate.

$S_2$ is the sensible heat of the steam at lower pressure (at which it has been flashed).

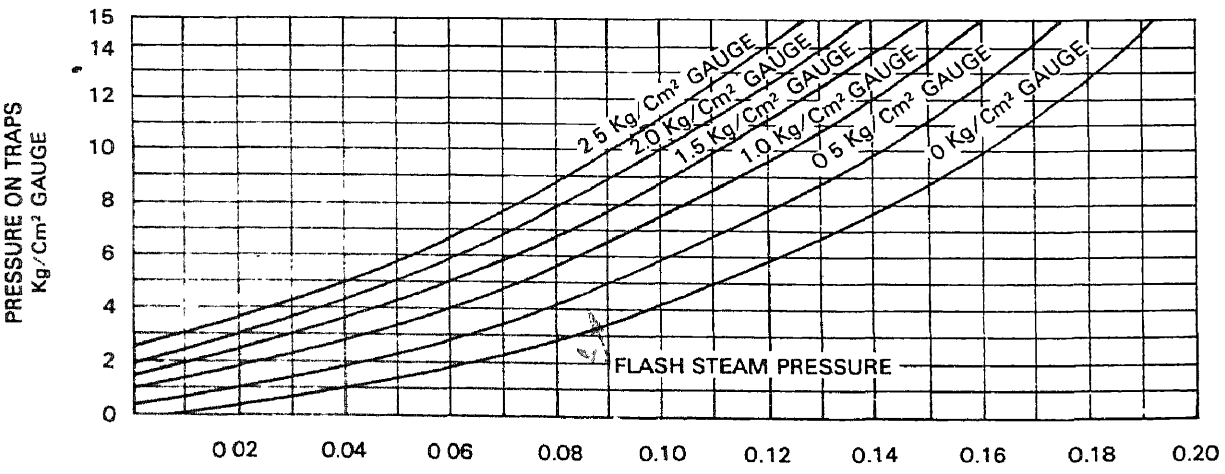
$L_2$ is the latent heat of flash steam (at lower pressure).

Alternatively, it can be determined from the graph given in Fig. 10. For example, if condensate at 11 kg/cm², about 5% by weight of the condensate could be generated as flash steam. This steam can be used on low pressure applications like direct injection and can replace an equal quantity of live steam that would be otherwise required. The higher the steam pressure and the lower the pressure of flash steam, the greater the quantity of flash steam that can be generated.

The demand for flash steam should exceed its supply, so that there is no build up of pressure in the flash vessel and the consequent loss of steam through the safety valve. Generally, the simplest method of using flash steam is to flash from a machine/equipment at a higher pressure to a machine/equipment at a lower pressure, thereby augmenting steam supply to the low pressure equipment (from the need of steam regularly through a reducing valve).

In general, a flash system should run at the lowest possible pressure so that the maximum amount of flash is available and the back pressure on the high pressure systems is kept as low as possible.

Flash steam from the condensate can be separated in an equipment called the 'flash vessel'. This is a vertical vessel as shown in Fig. 11. The diameter of the vessel is such that a considerable drop in velocity allows the condensate to fall to the bottom of the vessel from where it is drained out by a steam trap preferably a float trap. Flash steam itself rises to leave the vessel at the top. The height of the vessel should be sufficient enough to avoid water being carried over in the flash steam.



(Fig.10) —Kg FLASH PER Kg CONDENSATE

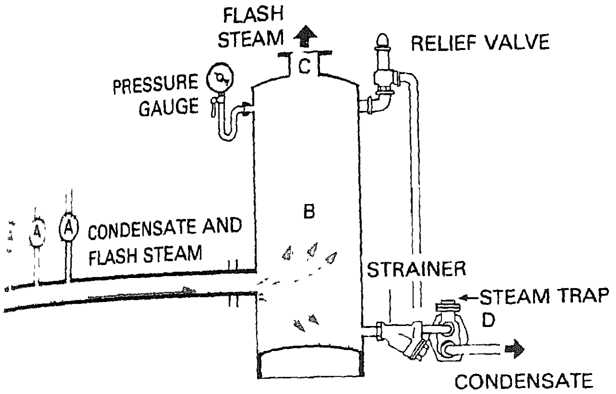
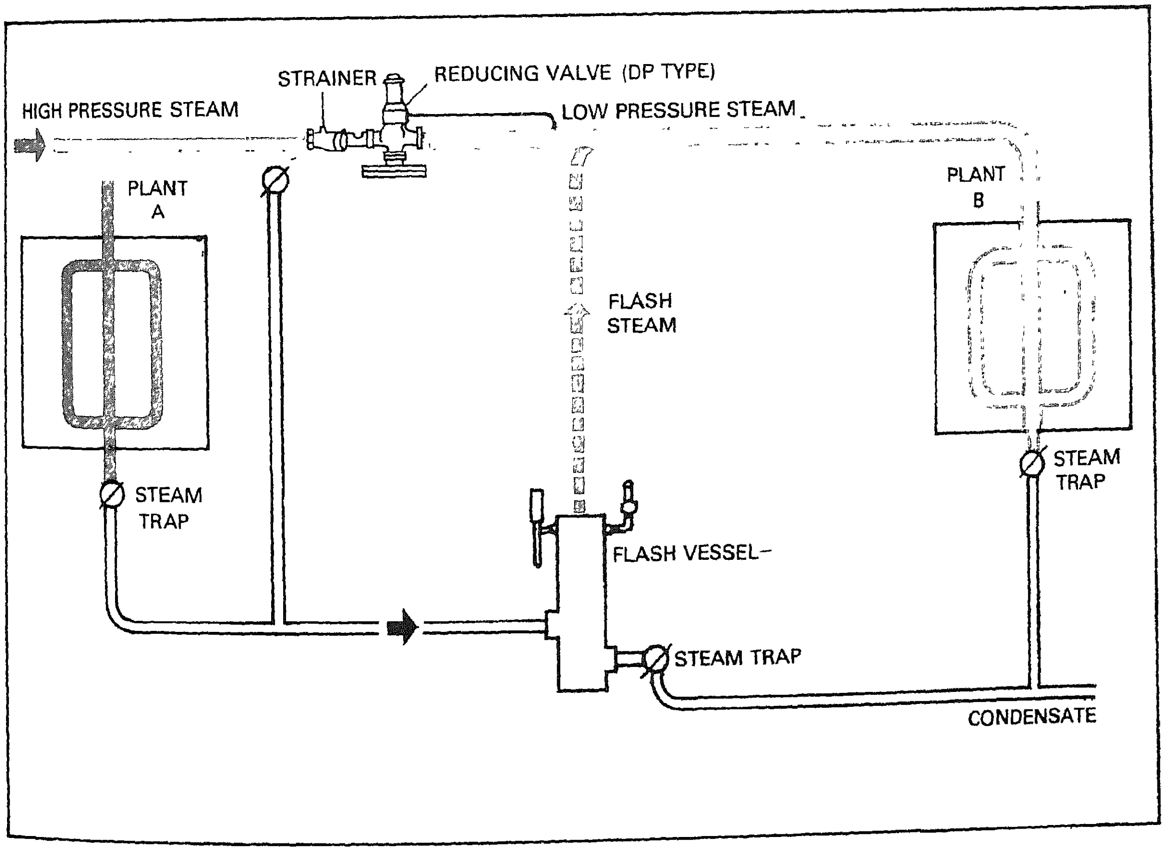


Fig 11 – FLASH VESSEL

The condensate from the traps (A) along with some flash steam generated passes through vessel (B). The flash steam is let out through (C) and the residual condensate from (B) goes out through the steam trap(D). The flash vessel is usually fitted with a 'pressure gauge' to know the quality of flash steam leaving the vessel. A 'safety valve' is also provided to vent out the steam in case of high pressure build up in the vessel.

### Typical application of flash vessel

For example, if we have a situation as shown in Fig. 12, such that there are two plants A and B operating simultaneously in a factory, Plant A needs high pressure steam and Plant B requires low pressure steam, the flash steam from the condensate of Plant A can be utilised in Plant B through a flash vessel reducing the requirement of high pressure steam which otherwise would be used in Plant B through the pressure reducing valve.



(Fig.12)

## 10. Proper selection and maintenance of steam traps

It has been seen that the main causes of unsatisfactory condensate removal include the choice of the wrong type of steam trap for the application, the use of a trap incorrectly sized for the load and pressure conditions, and bad installation. Any of these factors can seriously reduce the plant output. If the user of steam traps is fully aware of traps, their functions and types, correct application and installation, the poor equipment performance, waste of steam and high maintenance cost of the traps can easily be avoided.

The steam trap is an automatic valve capable of distinguishing between condensate and live steam. It oper to discharge the former (condensate) but closes to trap the latter (steam).

The difference between condensate and steam is sensed several ways. One group of traps detect the difference in density. Another group react to a difference in temperature and the third rely on the difference in flow characteristics

### Classification of commonly used steam traps

| **Mechanical Traps** | **Thermostatic Traps** | **Thermodynamic Traps** | **General** |
|---|---|---|---|
| (Operates on the difference in density between condensate & steam.) | (Operates by sensing a difference in temperatures between condensate & steam.) | (Operates on the forces generated by flashing condensate and steam flowing through orifice.) | 1) Impulse Traps<br>2) Pilot Operated Traps<br>3) Labyrinth Traps<br>4) Orifice Plates<br>5) Ogden Pump, etc. |
| 1) **Float Traps:**<br>a) Plain Float<br>b) Trip Float<br>2) **Bucket Traps:**<br>a) Open-top bucket traps.<br>b) Inverted bucket traps. | 1) Balanced-Pressure Traps.<br>2) Liquid Expansion Traps.<br>3) Bimetal Traps. | | |

The various characteristics of steam traps are summarised in Table II on next page.

### Steam trap selection

The selection of a steam trap for a particular application depends on the process conditions (like temperature, pressure and quantity of condensate, etc.) and derives from the judgement based on past experience. However, a widely accepted guide for this purpose is given below to help the users in making an appropriate decision.

| **S.No.** | **Application** | **First choice** | **Second choice** |
|---|---|---|---|
| 1) | Steam Mains & Separators | T.D. | Ogden |
| 2) | Steam Mains, Horizontal Runs | T.D. | Ogden |
| 3) | Branch Mains to Process | T.D. | T.S.U. |
| 4) | Heat Exchanger (Calorifiers) | F.T. | Ogden |
| 5) | Steam Radiator | I.B.T. | T.D. |
| 6) | Unit Heaters | F.T. | F.T. |
| 7) | Boiling Pans (Pedestal) | T.S.U. | F.T. |
| 8) | Boiling Pans (Fixed) | F.T. | T.D. |
| 9) | Boiling Pans (Tilting) | F.T.(SLR) | F.T. (SLR |
| 10) | Boiling Pans (Extra Rapid Tilting) | F.T.(SLR) | T.S.U |
| 11) | Brewing Copper | F.T. | Ogden |
| 12) | Drying Units (Short) | T.D. | T.S.U. |
| 13) | Drying Units (Long) | T.D. | T.S.U. |
| 14) | Dryers-Cylinder | F.T.(SLR) | F.T. (SLR |
| 15) | Digesters | F.T. | Ogden |
| 16) | Multi-Platen Presses (Parallel individual connections) | T.D. | T.D. |
| 17) | Oil Storage Tanks | Ogden | T.S.U. |
| 18) | Tracer Lines | T.D. | T.D. |
| 19) | Steam Hammers | T.D. | T.D. |
| 20) | Hot Tables (Process) | T.S.U. | T.D. |

**Legend:** T.D. ... Thermodynamic Traps
Ogden ... Ogden Traps
F.T. ... Float Traps
F.T. (SLR) ... Float Traps with steam lock release
T.S.U. ... Thermostatic Unit

## Table-II

## Characteristics of steam traps

| TYPE OF TRAP | TYPE OF DISCHARGE | OPENING FORCE | CLOSING FORCE | TEMPERATURE OF CONDENSATE | DISCHARGE AIR | WITHSTAND WATER HAMMER | STRAINER BEFORE TRAP | CONDENSATE DRAINED | WILL LIFT CONDENSATE | DAMAGE BY FROST | CHECK VALVE BEFORE TRAP | SUITABLE FOR SUPERHEATED STEAM | SUITABLE FOR VARYING PRESSURE |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Plain float | Continuous | Buoyancy | Float weight | Saturation | No | No | Highly desirable | Instantly | Yes | Yes | No | Yes | Yes |
| Trip float | Intermittent | Buoyancy | Float weight | *Saturation* | No | No | *Desirable* | As formed | Yes | Yes | No | Yes | Yes |
| Open bucket | *Intermittent* | Weight of bucket | Buoyancy | Saturation | No | Yes | Not *essential* | As formed | Yes | Yes | Yes | Yes | Yes |
| Inverted bucket | Intermittent | Weight of bucket | Buoyancy | Saturation | Yes | Yes | Not essential | As formed | Yes | Yes | Yes | Yes | Yes |
| Metallic expansion | Semi-continuous | Metallic contraction | Metallic expansion | Pre-set temperature | Yes | Yes | Highly desirable | At pre-set temperature | Yes | No | No | Yes | No |
| Liquid expansion | Semi-continuous | Steam *pressure* | Liquid expansion | Pre-set *temperature* | Yes | Yes | Highly *desirable* | At pre-set temperature | Yes | No | No | Yes | No |
| Balanced pressure expansion | Semi-continuous | Differential pressure | Differential pressure | Below saturation | Yes | No | Highly desirable | After cooling | Yes | No | No | No | Yes |
| Relay float, bucket, bottle. | Continuous if compensated | Outside *source* unlimited | Outside source unlimited | Saturation | No | — | Desirable | As formed | Yes | Yes | No | Yes | Yes |
| Pumping or lifting | Intermittent | — | — | Any temperature below steam temperature | No | — | Not essential | As formed | Yes | Yes | *In trap* | Yes | Yes |

## Installation of steam traps

In most cases, trapping problems are caused by bad installation rather than by the choice of the wrong type or faulty manufacture. To ensure a trouble-free installation, careful consideration should be given to the drain point, pipe sizing, air venting, steam locking, group trapping vs. individual trapping, dirt, water hammer, lifting of the condensate, etc.

### 1) Drain point

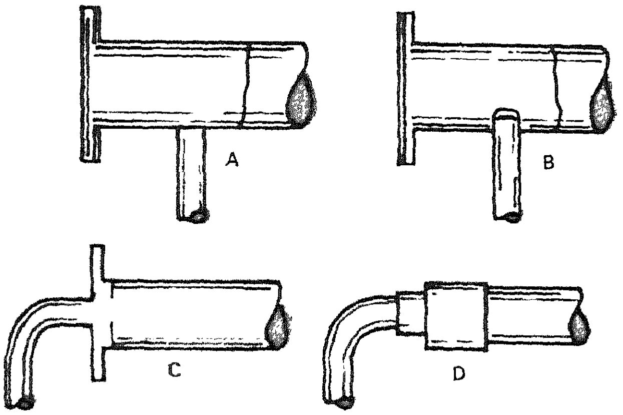
The drain point should be so arranged that the condensate can easily flow into the trap. This is not always appreciated. For example, it is useless to provide a 15mm drain hole in the bottom of a 150mm steam main, because most of the condensate will be carried away by the steam velocity. A proper pocket at the lowest part of the pipe line; into which the condensate can drop; of at least 100mm diameter is needed in such cases.
Fig. 13 and 14 show the wrong and the correct practices in providing the drain points on the steam lines.

### 2) Pipe sizing

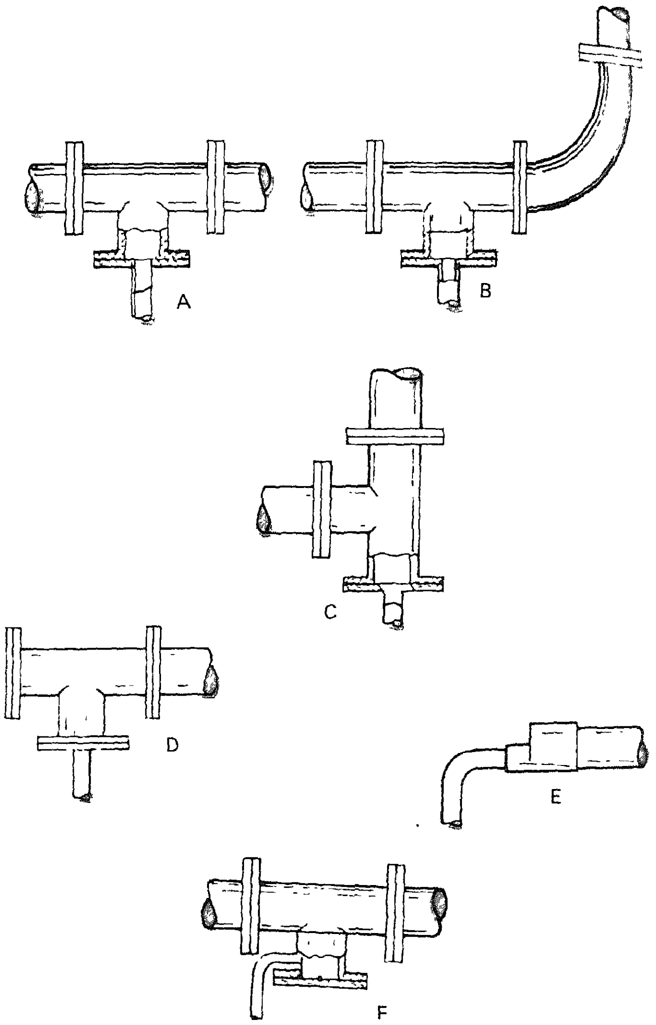
The pipes leading to and from steam traps should be of adequate size. This is particularly important in the case of thermodynamic traps, because their correct operation can be disturbed by excessive resistance to flow in the condensate pipe work. Pipe fittings such as valves, bends and tees close to the trap will also set up excessive back-pressures in certain circumstances.

### 3) Air binding

When air is pumped into the trap space by the steam, the trap function ceases. Unless adequate provision is made for removing air either by way of the steam trap or a separate air vent, the plant may take a long time in warming up and may never give its full output.



(Fig.13) — WRONG WAYS OF DRAINING PIPES



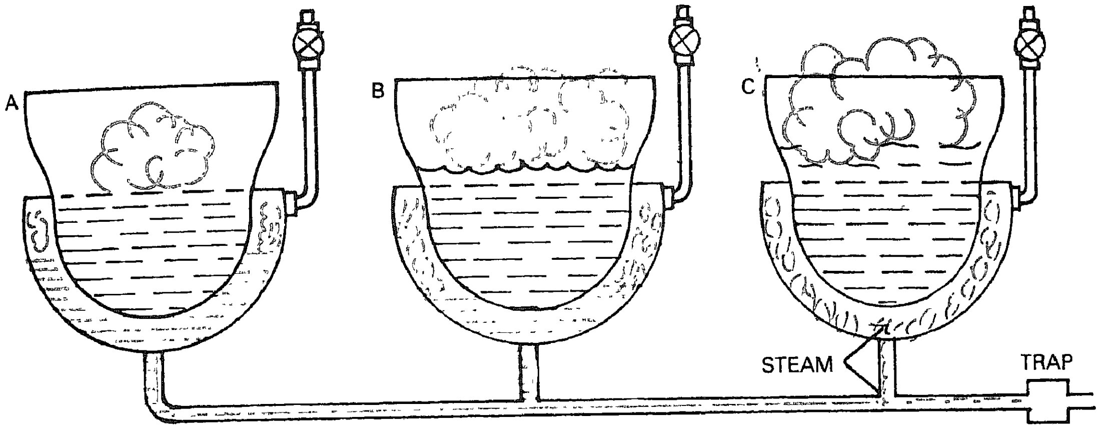
(Fig.14) — RIGHT WAYS OF DRAINING PIPES

### 4) Steam locking

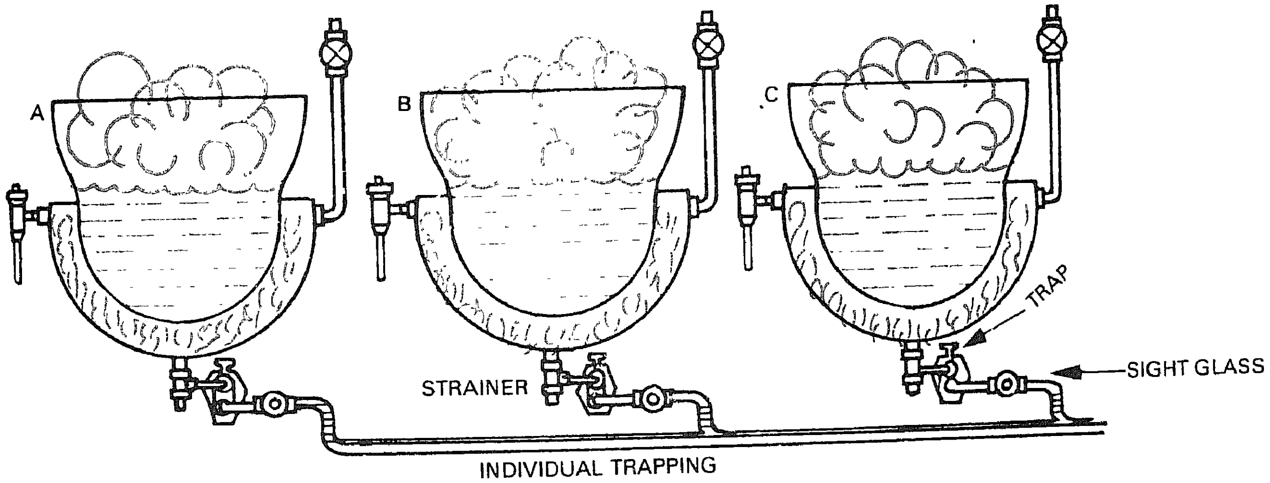
This is similar to air binding except that the trap is locked shut by steam instead of air. The typical example is a drying cylinder. It is always advisable to use a float trap provided with a steam lock release (F.T. SLR) arrangement.

### 5) Group trapping vs. individual trapping

It is tempting to try and save money by connecting several units to a common steam trap as shown in Fig. 14(a). This is known as group trapping. However, it is rarely successful, since it normally causes water-logging and loss of output.



(Fig.14a) — GROUP TRAPPING



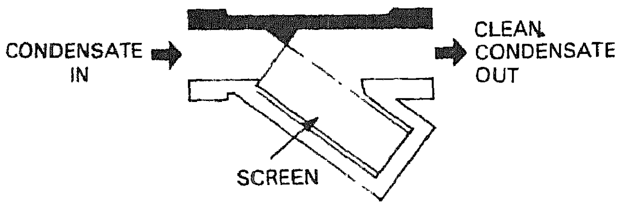
INDIVIDUAL TRAPPING

Fig.14b)—COMPARISON OF GROUP & INDIVIDUAL TRAPPING

The steam consumption of a number of units is never the same at a moment of time and therefore, the pressure in the various steam spaces will also be different. It follows that the pressure at the drain outlet of a heavily loaded unit will be less than in the case of one that is lightly or properly loaded. Now, if all these units are connected to a common steam trap, the condensate from the heavily loaded and therefore lower pressure steam space finds it difficult to reach the trap as against the higher pressure condensate produced by lightly or properly loaded unit. The only satisfactory arrangement, thus would be to drain each steam space with own trap and then connect the outlets of the various traps to the common condensate return main as shown in Fig. 14(b).

## 6) Dirt

Dirt is the common enemy of steam traps and the causes of many failures. New steam systems contain mill scale, castings and, weld metal and pieces of packing and jointing materials, etc. When the system has been in use for a while, the inside of the pipework and fittings, which is exposed to corrosive condensate can get rusted. Thus, rust in the form of a fine brown powder is also likely to be present. All this dirt will be carried through the system by the steam and condensate until it reaches the steam trap. Some of it may pass through the trap into the condensate system without doing any harm, but inevitably, the remaining dirt will eventually jam the trap mechanism. It is advisable to use a strainer (Fig. 15) positioned before the steam trap to prevent dirt from passing into the system.



(Fig. 15) — STRAINER

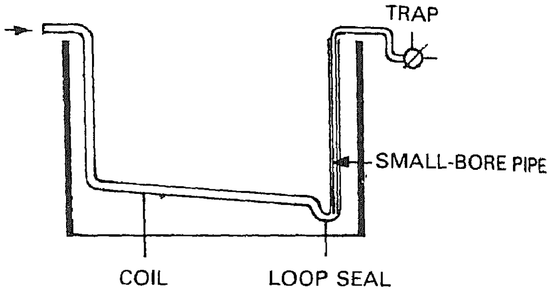
### 7) Water hammer

A water hammer in a steam system is caused by condensate collection in the plant or pipework. Picked up by the fast moving steam and carried along with it, when this collection hits obstructions such as bends, valves, steam traps or some other pipe fittings, the resulting shock is likely to cause severe damage to fittings and equipment and result in leaking pipe joints. The problem of water hammer can be eliminated by positioning the pipes so that there is a continuous slope in the direction of flow. A slope of at least 12mm in every 3 metres is necessary, as also an adequate number of drain points every 30 to 50 metres.

### 8) Lifting the condensate

In the interest of energy and treated water savings, every effort should be made to recover and re-use the condensate. Generally, this means lifting the condensate into a return main above the equipment. There may also be a case where the layout of the plant dictates that the steam traps be fitted above the equipment being drained. Wrong installation can lead to trouble. Because of the back pressures imposed upon the steam trap, it is often better not to lift the condensate directly from the trap, but to let it flow by gravity to a pump or a pumping trap which can then do the lifting. However, if it is decided that the condensate has to be lifted by its own pressure at the trap, it is important to ensure that the installation is correctly arranged.

Figure 16 shows a desirable arrangement of condensate draining and lifting. The rising pipe coil is looped to form a water seal. A small bore pipe is then passed through a steam tight joint at the top of the rising pipe, and its end is pushed well into the loop seal. The trap is fitted as close to the top of this pipe as possible. The water seal now makes it near impossible for the steam to enter the pipe leading up to the trap, and the small bore of this pipe ensures that the water column rises steadily due to steam bubbles.



(Fig. 16) — COIL-HEATED TANK CORRECT LAYOUT

## Maintenance of steam traps

Dirt is one of the most common causes of steam traps blowing steam. Dirt and scale are normally found in all steam pipes. Bits of jointing material are also quite common. Since steam traps are connected to the lowest parts of the system, sooner or later this foreign matter finds its way to the trap. Once some of the dirt gets logged in the valve seat, it prevents the valve from shutting down tightly thus allowing steam to escape. The valve seal should therefore be quickly cleaned, to remove this obstruction and thus prevent steam loss.

In order to ensure proper working, steam traps should be kept free of pipe-scale and dirt. The best way to prevent the scale and dirt from getting into the trap is to fit a strainer before each trap. The strainer element is a detachable, perforated or meshed screen enclosed in a metal body. It should be borne in mind that the strainer collects dirt in the course of time and will therefore need periodic cleaning.

It is of course, much easier to clean a strainer than to overhaul a steam trap (Fig. 15).

At this point, we might mention the usefulness of a sight glass fitted just after a steam trap. Sight glasses are useful in ascertaining the proper functioning of traps and in detecting leaking steam traps. In particular, they are of considerable advantage when a number of steam traps are discharging into a common return line. If it is suspected that one of the traps is blowing steam, it can be quickly identified by looking through the sight glass.

In most industries, maintenance of steam traps is not a routine job and is neglected unless it leads to some definite trouble in the plant. In view of their importance as steam savers and to monitor plant efficiency, the steam traps require considerably more care than is given. One may consider a periodic maintenance schedule to repair and replace defective traps in the shortest possible time, preferably during regular maintenance shut downs in preference to break down repairs.

### Steam trap capacity

The condensate discharge capacity of a steam trap depends mainly on three factors, viz. the size of the valve orifice, the differential pressure across it and the temperature of the condensate. It does not depend on the size of the pipe connections. But in practice, it is seen that traps are ordered on the basis of the pipe connections and not on actual process conditions.

Careful consideration should be given to the factors responsible for trap discharge capacity. For the actual discharge capacity at various differential pressures, the manufacturers' booklets should be consulted.

As a general rule, traps should not be too oversized. There are some types, such as thermodynamic traps, where the cycling rate increases if the trap is oversized, leading to rapid wearing down of the moving disc. Similarly, in very lightly loaded inverted bucket traps, the rate will increase because steam passing through the vent hole in the bucket condenses in the body. This is wasteful, if the trap is oversized. Finally, oversized traps which are physically larger than they need be, increase the radiation loss.

## 11. Proper sizing of steam and condensate pipelines

It must be remembered that there is always a right size for the steam pipe for the amount of steam it has to carry at a particular pressure. If the size is too small, then a high pressure drop as well as steam starvation at the using end will be the result. If it is too large, the capital cost of installation will unnecessarily be high, as will be the running cost due to the higher radiation losses from the larger surfaces.

### Sizing of short branch lines

For sizing short branch lines, to avoid excessive pressure drops, it is recommended that the pipe sizing be based on a steam velocity of about 15m/sec. At velocities higher than this, for instance 25 to 30m/sec., there would be considerable noise and the erosion would be greater particularly when the steam is wet.

### Sizing of long steam mains

A sizing of steam mains based upon a velocity of 15m/sec. may lead to unacceptably high pressure drops due to heavy friction losses in long lengths of pipelines. The pressure at the receiving end would be too low. In such cases, the mains should be sized on the basis of pressure drop considerations.

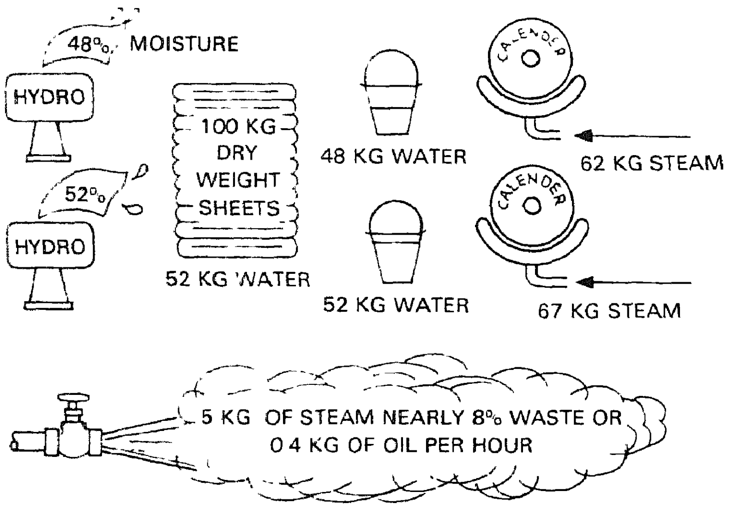
### Condensate pipe sizes

If the condensate pipes are not sized properly, they may either impose unacceptably high back pressure on the traps when they are undersized, or a heavy capital investment when they are unnecessarily oversized. It should be remembered that a trap will have to handle air and flash steam in addition to the condensate from the process equipment at the time of start-up. This is followed by a large amount of relatively cool condensate (the starting load is usually two or even three times the normal running load). As normal running conditions are established, the volume of water reduces but since the pressures are higher, larger quantities of flash steam will have to be handled. As a good thumb rule, it is best to size a condensate pipe as if it were carrying water under starting conditions only. It would then have adequate capacity to carry the condensate, as well as flash steam, under running conditions and to allow for the discharge of air at start-ups. If the starting load is not known, it may be assumed, under average conditions, to be twice the running load. An appropriate size has to be chosen keeping the allowable back pressure in mind. All pipelines should preferably have a fall in the direction of the condensate flow. If the fall in a water pipe is graded so that the fall per metre is equal to or greater than the frictional resistance per metre, then the water will flow freely without causing back pressure on the traps.

## 12. Reducing the work to be done by steam

When the steam reaches the place where its heat is required, it must be ensured that the steam has no more work to do than is absolutely necessary. Air-heater batteries, for example, which provide hot air for drying, will use the same amount of steam whether the plant is fully or partly loaded. So, if the plant is running only at 50 per cent load, it is wasting twice as much steam (or twice as much fuel) than necessary.

Always use the most economical way of removing the bulk of water from the wet material. Steam can then be used to complete the process. For this reason, hydro-extractors, spin dryers, squeeze or calender rolls, presses, etc. are initially used in many drying processes to remove the mass of water. The efficiency with which this operation is carried out is most important. For example, in a laundry for finishing sheets (100 kg/hr. dry weight), the normal moisture content of the sheets as they leave the hydro-extractor, is 48% by weight.



STEAM WASTAGE DUE TO INSUFFICIENT MECHANICAL DRYING

(Fig.17)

Thus, the steam heated iron has to evaporate nearly 48 kgs of water. This requires 62 kgs of steam. If, due to inefficient drying in the hydro-extractor, the steam arrive at the iron with 52% moisture content i.e. 52 kgs of water has to be evaporated, requiring about 67 kgs of steam. So, for the same quantity of finished product, the steam consumption increases by 8 per cent. This is illustrated in Fig. 17.

REFERENCE:

1. The Efficient Use of Steam—Oliver Lyle, HMSO, London
2. Spirax Sarco Manuals—Spirax Sarco Ltd., Cheltenham GL 53 8ER.
3. Fuel Economy Hand Book—NIFES, London.
4. The Efficient Use of Steam—General Editor, P.M. Goodall, Westbury House, England.

**This booklet is one of a series on fuel oil conservation, others in the series are listed below:**

1) Storage, handling and preparation of fuel oil.
2) Efficient generation of steam.
3) Efficient utilisation of steam.
4) Fuel economy in furnaces and waste heat recovery.
5) Refractories.
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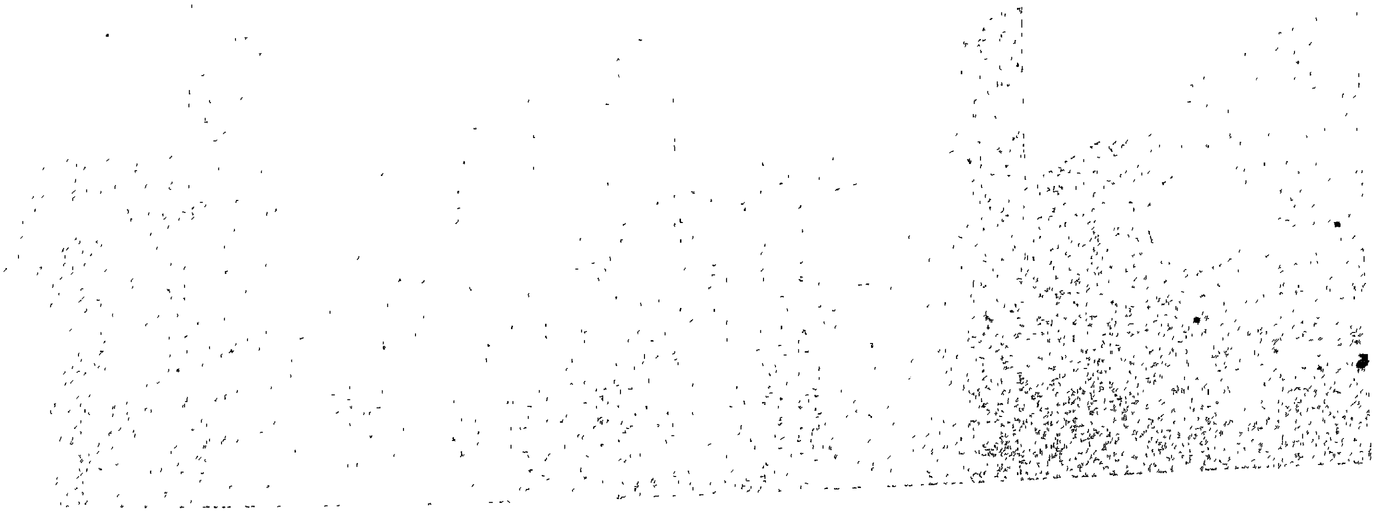
# 5

# Fuel economy in furnaces and waste heat recovery



## Introduction

In the context of the oil crisis and high cost of fuel oil, the subject of fuel economy and waste heat recovery now requires due importance from users of industrial furnaces. Fuel costs constitute about 40 per cent of the total value added during the process of manufacture in fuel-intensive industries such as glass and ceramics, forging, re-rolling,, ferrous and non-ferrous foundries, galvanizing, and several other applications.

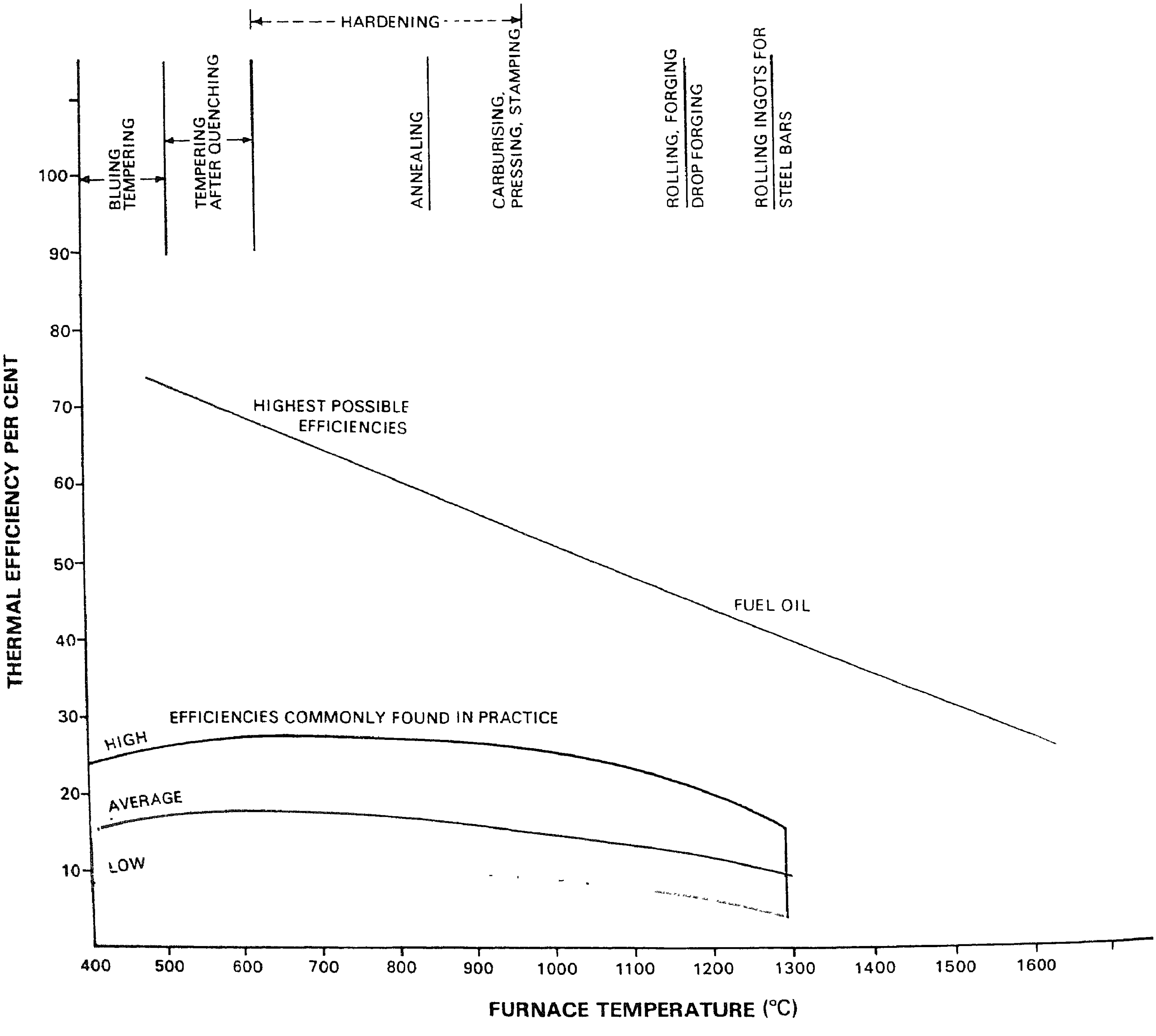
The scope of fuel savings to the tune of 30 to 40 per cent by adoption of first aid and long term conservation measures has been amply demonstrated by PCRA's experiences in several Indian Engineering industries.

## Fuel consumption and heat economy

The performance of a furnace installation can be expressed in various ways, the ultimate aim being the determination of the total quantity of fuel required to perform the required operation.

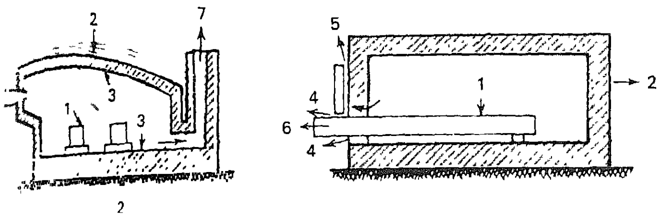
The term 'efficiency' in an industrial furnace, when used in the true sense, has reference to heat cost per unit weight of finished saleable product, or as the quantity of fuel expended to heat a unit weight of stock. While the efficiency in a boiler ranges from 60 to 85 per cent, the efficiency of furnaces are some times as low as 5 per cent. One reason for the difference in the efficiency between boilers and industrial furnaces is in the final temperature of the material being heated. Gases can give up heat to the charge only as long as they are hotter than the charge. Consequently, flue gases leave industrial furnaces at a very high temperature. This factor is responsible for low furnace efficiencies.

The ideal and common efficiencies of Industrial furnaces are shown in Fig.1.



(Fig. 1)—**IDEAL COMMON EFFICIENCIES OF INDUSTRIAL FURNACES OF THE INTERMITTENT OR BATCH TYPE**

In order to have a clear understanding of the distribution of heat in a simple furnace, let us examine Fig.2 below:



FLOW OF HEAT IN A FURNACE

| | |
|---|---|
| 1 | STOCK |
| 2 | GROUND & SURROUNDINGS |
| 3 | HEARTH |
| 4 | CRACKS AND OPENINGS |
| 5 | DOOR |
| 6 | PORTION OF STOCK PROTRUDING OUTSIDE |
| 7 | STACK |

**Flow of heat in a furnace**

The fuel oil required for combustion is cleaned, preheated and burnt in the combustion zone of the furnace. It would be desired that most of the heat liberated be imparted to the stock but the heat goes elsewhere. Some of it passes into the furnace wall and hearth as shown in Fig.2. Another portion of heat is lost to the surroundings by radiation and convection from the outer surface of the walls or by conduction, into the ground. Heat, is also radiated through cracks or other openings and furnace gases pass out around the door, frequently burning in the open and carrying off heat. Heat is also lost every time the door is opened. Another form of heat dissipation is through the stock which protrudes out in certain cases. Finally, the bulk of the heat loss passes out along with the products of combustion, either in the form of sensible heat or as incomplete combustion. Fuel economy demands that the fraction of total heat that passes into the stock be as large as possible and that all the losses be minimised.

The purpose of finding out efficiency of a plant is to establish how well the plant is designed or run in comparison to another similar plant. If this view is accepted, then the efficiency of furnaces can be better assessed by measuring the amount of fuel required per unit weight of material.

## Factors affecting fuel economy

Various factors which affect fuel economy in industrial furnaces are:

1) Complete combustion with minimum excess air.
2) Proper heat distribution.
3) Operating at the desired temperature.
4) Reducing heat losses from furnace openings.
5) Minimising wall losses.
6) Control of furnace draught.
7) Optimum capacity utilization.
8) Waste heat recovery from furnace flue gases.

## 1. Complete combustion with minimum excess air

To achieve complete combustion of fuel with minimum excess air, a number of factors (such as proper selection and maintenance of control, excess air monitoring, air infiltration, pressure of combustion air) are to be considered. The magnitude of stack losses with different quantities of excess air in the case of a furnace carrying away flue gases at 900°C, is depicted in Table. I

### Table-I

**Table showing excess air and heat loss**

| Excess air percentage | Percentage of total heat in the fuel carried away by waste gases. (flue gas temperature-900°C) |
|---|---|
| 25 | 48 |
| 50 | 55 |
| 75 | 63 |
| 100 | 71 |

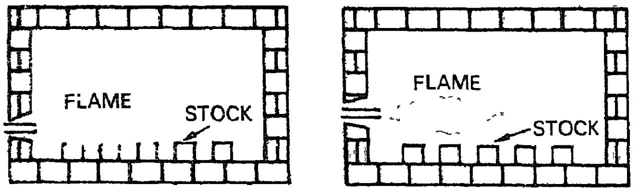
Besides abnormal increase in stack losses, with the increase in excess air, the ingress of too much excess air lowers the flame temperature and consequently reduces furnace temperature and the heating rate. If too little excess air were used, combustion would be incomplete and chimney gases will carry away unused fuel potential in the form of unburnt combustible gases such as carbon monoxide, hydrogen and unburnt hydrocarbons which should have otherwise been usefully burnt in the combustion chamber.

Various considerations for better preparation of fuel oil are adequately covered in our booklet entitled 'Storage, handling and preparation of fuel oil'. The booklet entitled 'Combustion of fuel oil and burners—operation and maintenance' covers various consideration affecting combustion, selection, operation and maintenance of burners for minimizing excess air. These aspects are not being dealt with in this booklet.

## 2. Proper heat distribution

Ideally, a furnace should be designed so that in a given time, as much material as possible, be heated to as uniform a temperature as possible with the minimum fuel firing rate. To achieve this, the following points should be considered.

i) The flame should not touch the stock and should propogate clear of any solid object. Any obstruction whatsoever, deatomises the fuel particles thus affecting combustion and creating black smoke. If the flame touches the stock, the scale losses increase manifold (Fig. 3).



WRONG CORRECT

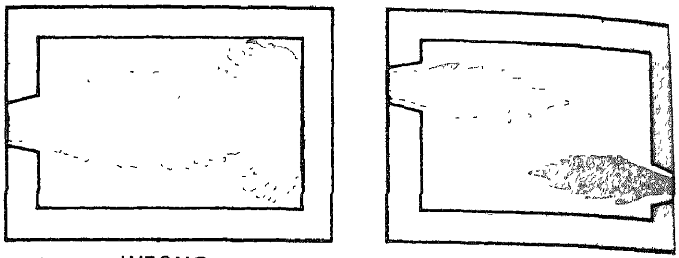
(Fig.3)—ALIGNMENT OF BURNERS IN FURNACES

ii) Refractories are leached if the flames touch any part of the furnace, as the incomplete combustion products can react with some of the refractory constituents at high flame temperatures.

iii) The flames from various burners in the combustion space should also stay clear of each other. If the flames intersect, inefficient combustion would occur. This can be controlled by staggering the burners of the opposite walls.

iv) The flame has a tendency to travel freely in the combustion space just above the material. In small reheating furnaces, the burner axis is never placed parallel to the hearth but always at an upward angle. Every precaution should be taken to ensure that the flame never hits the roof.

v) The larger burner produces a long flame which may be difficult to contain within the furnace walls. More burners of less capacity give better distribution of heat in the furnace, and also reduce scale losses while increasing furnace life as shown in Fig. 4.



WRONG CORRECT

(Fig.4) — HEAT DISTRIBUTION IN FURNACES

vi) For smaller reheating furnaces, it is advisable to maintain a long flame with a golden yellow colour while firing furnace oil for uniform heating. It should be seen that flame should not be so long that it enters the chimney and comes out at the top or through doors. This occurs when excessive oil is fired normally to increase the production rate. Such an operational practice in the real sense helps marginally.

A major portion of the additional oil fired is carried away into the stack as waste heat. It is, therefore, advisable to contain the flame within the furnace.

vii) It is also desirable to provide the combustion volume adequate to the heat release rate. As a thumb rule, for direct fired heating furnace, a heat release equivalent to 700,000 Kcal per hr. per cubic metre of combustion volume may be used.

## 3. Operating at the desired temperature

For any given industrial heating or melting operation, there is an optimum temperature for operation of the furnace. Table II below shows operating temperature for different furnaces.

### Table-II

**Operating temperature for different furnaces**

| | |
|---|---|
| Slab reheating furnaces | 1200°C |
| Rolling Mill furnace | 1180°C |
| Bar Furnace for sheet mill | 850°C |
| Bogey type annealing furnace | 650 - 750°C |
| Bogey type roll annealing furnace | 1000°C |
| Small forging furnace | 1150°C |
| Rotary iron melting furnace | 1550°C |
| Enamelling furnace | 820 to 860°C |

Operating at too high a temperature will not only mean unnecessary waste of fuel in terms of heat, but will also cause overheating of the stock, its spoilage or excessive oxidation and decarburization as well as over-stressing the refractories. Normally, in most of the plants, the decision on the proper operating temperature is left to the judgement of the operators. In order to avoid human error, provisions for temperature control instruments should be made.

The furnaces are often run without any temperature controls, often with 'on-off control', which is extremely harmful to the optimum performance of the furnace. In the off condition, only the atomising air enters the furnace bringing down its temperature rapidly so that when the oil firing proces is recommended, the amount of oil supplied to the furnace to bring up the temperature, is much more than would be necessary had the furnace been operated on a proportional control'.

## 4. Reducing heat losses from furnace openings

In oil fired furnaces, substantial heat losses occur through furnace openings. For every large opening, heat loss due to openings may be calculated by computing black body radiation at furnace temperature, and multiplying these values with emissivity (usually 0.8 for furnace brick work), and the factor of radiation through openings. The black body radiation losses can be directly computed from the curve as seen in Fig.5. Factor for radiation through openings can be determined with the help of nomogram as in Fig.6.

Heat loss through openings = Area of cross section × Factor of radiation through openings × Black body radiation.

**Example**

A furnace front at 1000°C is bricked up with a 115mm wall through an observation opening (peephole) of 65mm×115mm which is left open. The heat losses through the opening are worked as under:

Area of opening = 6.5 × 11.5 = 74.75 cm$^2$

D/X Ratio of sides of rectangle = 115/65 = 1.77

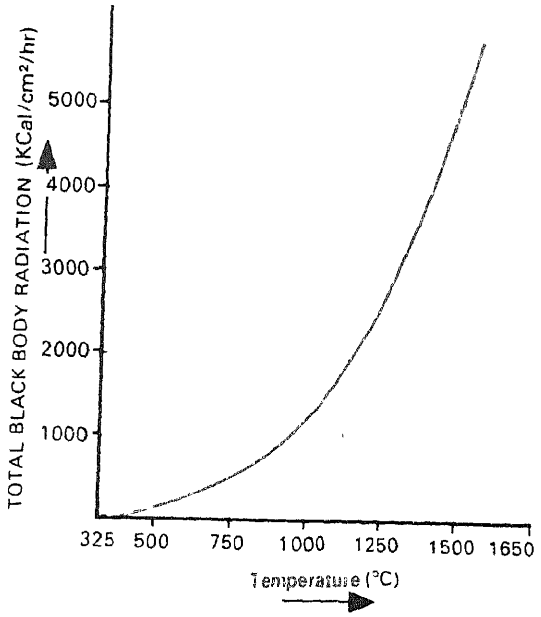
Factor for radiation through opening = 0.71 (from Fig.6)

Emissivity = 0.8

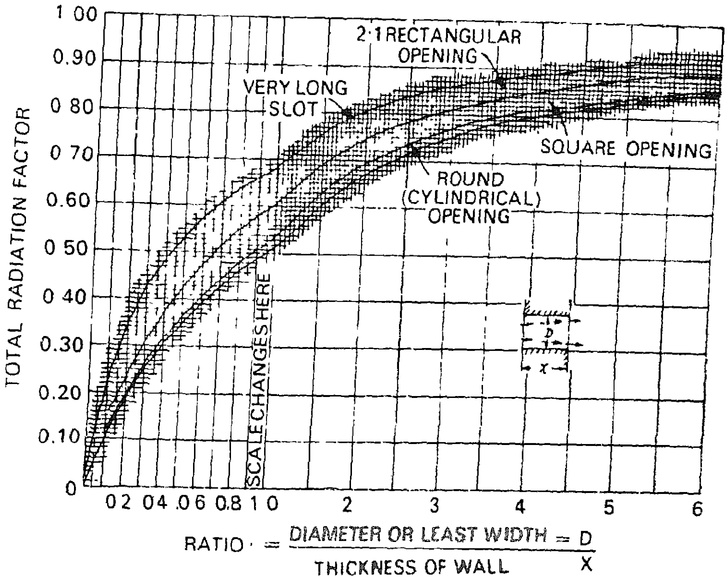
Black Body Radiation corresponding to 1000°C = 1200 Kcal/cm$^2$/hr. (from Fig.5).

Therefore heat loss = 74.75 × 1200 × 0.71 × 0.8 = 51,000 Kcal/hr.

Equivalent fuel oil loss = 5.4 lit/hr



(Fig.5) — BLACK BODY RADIATION



(Fig.6) — RADIATION THROUGH OPENINGS OF VARIOUS SHAPES

Assuming the heat carried in the stack to be 60% of heat supplied

equivalent oil savings = 13 litres/hour.

In one of the industries for melting 500 kg of gun metal per hour in a reverberatory furnace, it was found that there was as much flame burning outside the furnace as it was inside. This was being practised by the operators thinking that melt time was shorter if the flame leaps out.

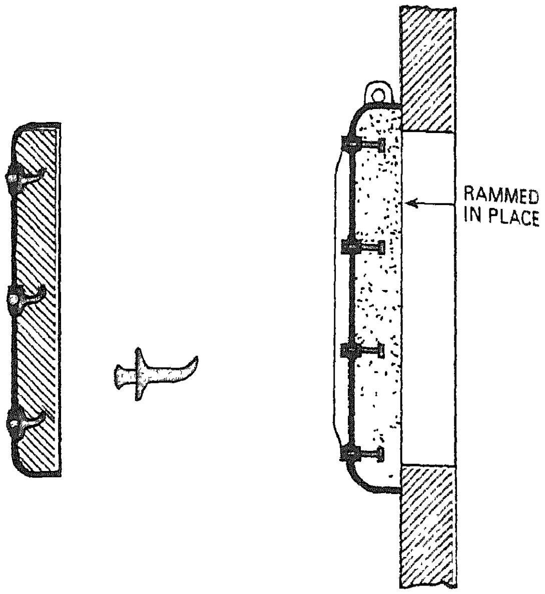
In order to stop this wasteful practice, an experiment was conducted on two identical furnaces; gun metal to be melted was weighed and charged to both furnaces at the same time. One furnace was operated as it was normally done by the operators, and the other furnace was operated by confining the flame within the furnace and closing all openings with refractory bricks. In both cases, the time taken and fuel consumed to melt the charge was noted. The exercise was repeated by interchanging the furnaces and the time taken and fuel consumed noted again.

The experiment revealed, to the surprise of the management of the industry and their operators, that the time taken to melt the charge by controlling the flame within the furnace was the same as in the case of the furnace with flames leaping out. But most important of all was that the fuel consumption was almost half where the flames were contained within, as opposed to the other furnace where flames leapt out.

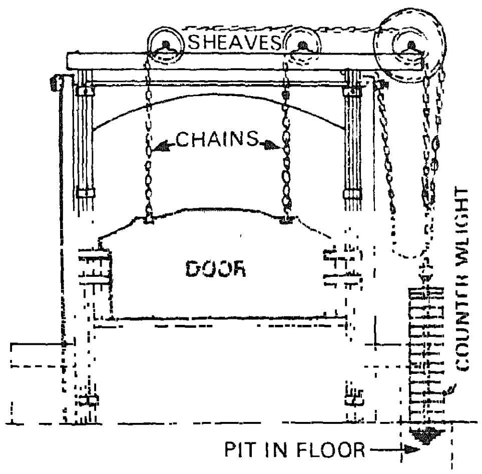
Hence it is imperative that all unnecessary openings of the furnaces be sealed and the flame be contained within the furnace.

Doors should be tightly shut and made of light material that is durable and heat proof. Doors that are hinged or swinging type may be provided. To minimise heat losses, the refractory lining should be sufficiently thick and of good insulation quality. Fig.7 illustrates the method of holding cement in a door frame.

In order to reduce fatigue as well as to ensure ease in closing the opening, vertically lifting doors balanced by counter weights, should be used as shown in Fig 8.



(Fig 7) — METHODS OF HOLDING CEMENT IN DOOR FRAME



(Fig 8) —FURNACE DOOR LIFTING MECHANISM WITH COUNTER WEIGHT

# 5. Minimising wall losses

About 30-40% of the fuel input to the furnace generally goes to make up for heat losses in intermittent or continuous furnaces. The appropriate choice of refractory and insulation materials goes a long way in achieving fairly high fuel savings in industrial furnaces.

**Insulation for furnaces**

In industrial furnaces, fuel consumption can be substantially reduced by judicious application of external insulation. Several material with different combinations of heat insulation and thermal inertia should be considered to minimise heat losses through furnace walls. The use of insulating refractories of appropriate quality and thickness can cut down heat storage capacity of walls, and time required to bring the furnace to operating temperature by a much as 60-70 per cent in intermittent furnaces.

### Insulating materials

Insulating materials owe their lower conductivity to the pores, while their thermal inertia depends on the weight per unit volume of solids and its specific heat. There are, in general, three types of insulating bricks:

a) Products made from diatomaceous earth.
b) Products derived from vermiculite.
c) Refractory (fireclay or silica) based products.

The latter (c) are known as insulating refractories and are used as inner lining in furnaces.

There are two methods of insulation normally used for high temperature furnaces. When the furnace is operating continuously under severe condition of atmosphere or high temperature, a lagging of diatomaceous insulation.is placed behind a dense refractory base. In other installations where cleaner conditions or a lower temperature prevail, particularly in short cycle intermittent furnaces and kilns, the insulating material can itself form the refractory lining with no back up refractory bricks.

Materials of the latter type are highly porous refractory and have fair strength and spalling resistance, and can in general, be used up to a temperature as high as 1800°C.

Another class of materials (ceramic fibres) with very low conductivity, and extremely light weight, with the capacity to withstand thermal shocks can also be used in intermittent furnaces.

Various aspects, on heat savings through the choice of appropriate refractories and insulation, have been highlighted in a booklet in this series entitled 'Refractories'.

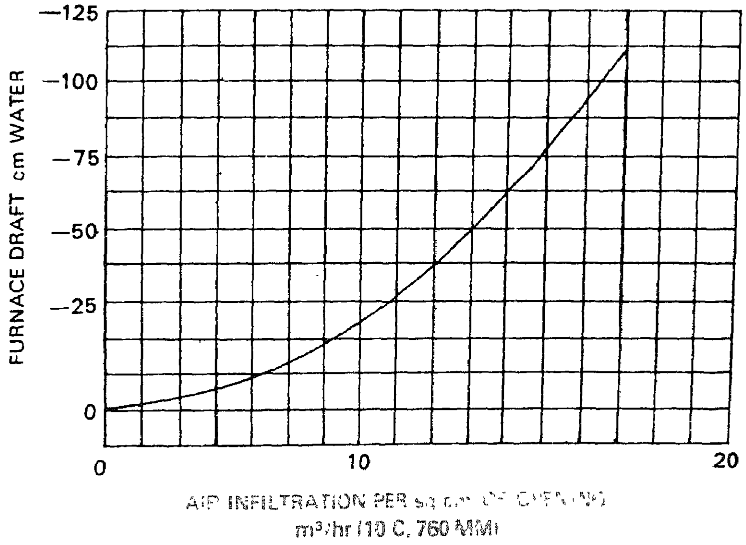
## 6. Control of furnace draught

In any furnace, the entrance of uncontrolled free air must be prevented. It pays to maintain a slight excess pressure inside the furnaces to avoid air infiltration. Large furnaces, especially those with stack draft, are equipped with pressure sensing devices which by relays and servomotors, adjust dampers or adjust the flow of protective gas into the furnace.

At furnace temperatures, oxygen attacks the common metals and forms oxides or scale. Carbon monoxides and hydrogen reduce the oxides to metal. On the basis of these considerations, the term "oxidizing atmosphere" and "reducing atmosphere" (both refering to products of combustion) were coined and adopted years ago.

Reducing atmospheres (excess of fuel) form less scale than that which is formed by oxidizing atmospheres (excess of air) but the scale is tight and adheres firmly. More scale is formed in oxidizing atmospheres but this scale is more easily removable.

The effect of air infiltration on furnace draught is illustrated in Fig. 9.

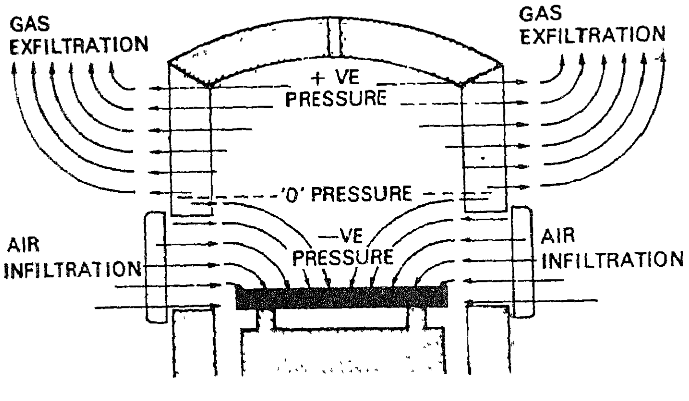


(Fig.9)— **EFFECT OF NEGATIVE PRESSURES ON AIR INFILTRATION**

If negative pressures exist in the furnace, air infiltration is liable to occur through the cracks and openings thereby affecting air-fuel ratio control. Tests conducted on apparently air tight furnaces have shown air infiltration up to the extent of 40%. Neglecting furnace pressure could mean problems of cold metal and non-uniform metal temperatures, which could affect subsequent operations like forging and rolling and result in increased fuel consumption.

The furnace pressure is constant in different parts of the furnace. The zero level in the furnace is the level at which the furnace pressure equalizes the atmospheric pressures. The effect of air pressure on the location of zero level is shown in Fig. 10.

It has been observed that minimum consumption of fuel occurs at considerably higher furnace pressures, than that required to keep zero level at the hearth. This phenomenon is due to exfiltration. Exfiltration is less serious than infiltration. Some of the associated problems with



(Fig 10) — **EFFECT OF PRESSURE ON THE LOCATION OF ZERO LEVEL AND INFILTRATION OF AIR.**

exfiltration are leaping out of flames, overheating of the furnace refractories leading to reduced brick life, increased furnace maintenance, burning out of ducts and equipments attached to the furnace, etc.

# 7. Optimum capacity utilisation

When the initial design of a furnace is considered, it is desirable that discussions take place with all parties involved in the process. The aim being to obtain the correct furnace for the jobs in hand. One factor which must be considered is whether the work can be processed in a continuous furnace or should a batch type be used.

If stock can be fed continuously at one end of a furnace and discharged through the other, then the overall efficiency will increase with load recuperation from the waste gas products.

If it is not possible to use a continuous furnace, then careful planning of the loads for batch type furnaces is essential. A furnace should be recharged as soon as possible (within the metallurgical and other physical limitations) to enable any residual furnace heat to be used.

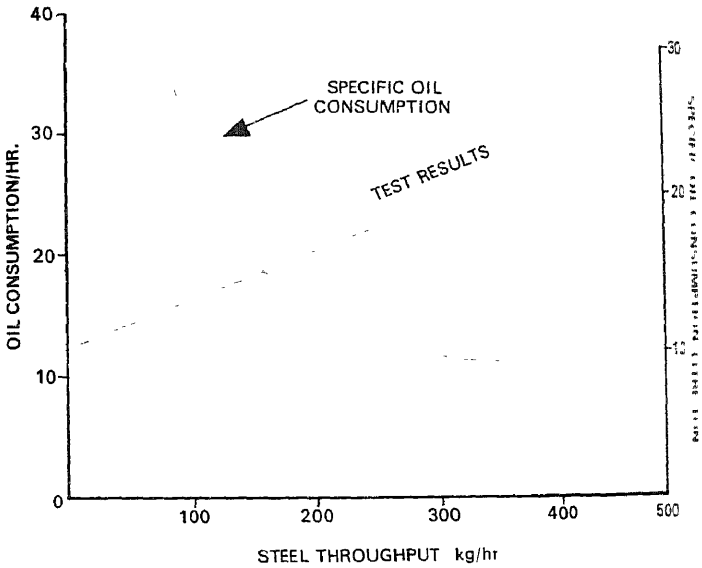
**Furnace loading**

One of the most vital factors affecting efficiency is loading. There is a particular loading at which the furnace will operate at maximum thermal efficiency. If the furnace is under-loaded, a smaller fraction of the available heat in the working chamber will be taken up by the load and therefore the efficiency will be low.

The best method of loading is generally obtained by trial, noting the weight of material put in at each charge, the time it takes to reach a given temperature and the amount of fuel used.

Care should be taken to load a furnace at the rate associated with optimum efficiency, although it must be realised that limitations to achieving this are sometimes imposed by work availability or other factors beyond operational control.

The "no-load" consumption to maintain a simple batch type furnace at 1300°C when empty is about 70% of that required to operate at the optimum loading rate.



(SLOT REHEATING FURNACE 1 35 m² HEARTH AREA TEMPERATURE 1300°C)

(Fig 11)

Fig 11 above indicates the effect of increased loading rates on thermal efficiency, and performance of a typical slot type reheating furnace for drop forgings. The heat balance computations are at different hearth loading values, given in Table III. The effect of loading on continuous furnace performances are tabulated in Table IV. This illustrates the advantage of operating the furnaces at the highest economic furnace loading. Hearth loading rates normally expected in good practices for some typical furnaces are given in Table V.

Table-III

## Effect of hearth loading on thermal balance and specific fuel consumption

| | Hearth loading (kg/m²/hr.) | | | |
|---|---|---|---|---|
| | **98** | **147** | **244** | **366** |
| Furnace output kg/hr | 125 | 187 | 312 | 468 |
| Heat in steel at 1200°C million Kcal/hr. = Hc | .026 | .039 | .065 | .097 |
| Heat in furnace structure million Kcal/hr. = Hs | .063 | .063 | .063 | .063 |
| Total Heat required: $\frac{Hc + Hs}{0.4} = Hl$ | 0 222 | 0.255 | 0.318 | 0.403 |
| Ratio of $\frac{\text{Heat to Steel}}{\text{Heat to Structure}} = \frac{Hc}{Hs}\%$ | 11.6 | 15.2 | 20.3 | 29.0 |
| Fuel consumption Million Cal/tonne | 1800 | 1384 | 1040 | 880 |
| Fuel and Financial Savings% | — | 23 | 42 | 51 |

Slot Type Reheating Furnace for Drop Forging
Effective Hearth Area: 1.277 metre².
Exit Gas Condition: 1320°C and 10% Excess Air
Total heat to structure: .063 million Kcal/hr, Heat in gas leaving furnace. 60%
Heat available in furnace: 40%

Table-IV

## Effect of loading on continuous furnace performance

| **Production Rate** | **Tonnes/hr.** | **10.0** | **5.0** | **3.0** | **1.0** |
|---|---|---|---|---|---|
| Heat to stock | million Cal | 1760 | 880 | 530 | 176 |
| Waste gas loss | " | 2520 | 1760 | 1510 | 1290 |
| Structure loss | " | 1760 | 1760 | 1760 | 1760 |
| Heat loss input | " | 6040 | 4400 | 3800 | 3226 |
| Specific heat consumption | million Cal/tonne | 604 | 880 | 1267 | 3226 |

### Table-V

### Typical hearth loading rates normally expected in good practice

| | Kg/m²/h |
|---|---|
| Heat treatment furnace | 147 — 195 |
| Annealing furnace | 195 — 293 |
| Drop stamping and forging | 293 — 390 |
| Continuous reheating | 342 — 489 |

**Placing of stock**

The disposition of the load on the furnace hearth should be arranged so that:

a) It receives maximum radiation from the hot surfaces of the heating chamber and the flames.
b) The hot gases are efficiently circulated around the heat receiving surfaces.
c) There should be adequate spacing between the billets. Overlapping of materials, results in non-uniformity of temperature and should be avoided.

Stock should not be placed in the following positions:

a) In the direct path of the burners or where flame impingement is likely to occur.
b) In an area which is likely to cause a blockage or restriction of the flue system of the furnace.
c) Close to any door openings where cold spots are likely to develop.

**Load residence time**

In the interest of fuel economy and work quality, the materials comprising the load should only remain in the furnace for the minimum stipulated time to obtain the required physical and metallurgical requirements.

When the materials attain these properties they should be removed from the furnace to avoid damage and fuel wastage. For heating steels, the general rule is that heat travels 3mm in 5 minutes. For cylindrical square bars, the prescribed heating rate is 20 minutes per 25 mm of diameter of mild steel; and 40 minutes per 25 mm of diameter for alloy steels. For annealing of steel, 60 minutes are needed per 25 mm of diameter or thickness. The above values hold for the furnaces where the stock size is relatively small with respect to the size of the furnace.

Furnaces should be operated at their optimum rated capacity to achieve best fuel economy. This involves proper co-ordination among the various departments, selection of appropriate size and type of the furnace and material handling system. Frequent breakdowns in the production machines make the furnace idle for lengthy periods, thus causing extra expenditure on fuel. Economy could be achieved by collecting an adequate sequence of charges, operating the furnace continuously at the most economical loading and then shutting down entirely for a given period if insufficient work is available. When shut down, all sources of air leakage should be minimised.

## 8. Waste heat recovery from furnace flue gases

In any industrial furnace the products of combustion leave the furnace at a temperature higher than the stock temperature. Sensible heat losses in the flue gases, while leaving the chimney, carry 35 to 55 per cent of the heat input to the furnace. Typical quantities of waste heat available in different operations are listed in Table VI below:

### Table-VI

| Furnace | | Temperature ( C) |
|---|---|---|
| Copper reverberatory furnace | : | 1100-1400 |
| Forge and billet heating furnace | : | 800-1100 |
| Glass melting furnace | : | 1000-1300 |
| Open hearth steel furnace air blown | : | 550- 700 |
| Furnace oxygen blown | : | 700-1150 |
| Annealing furnace | : | 600-1100 |
| Ceramic kilns (Down draft) | : | 70-1100 |

The higher the quantum of excess air and flue gas temperature, the higher would be the waste heat availability.

The sensible heat in flue gases can be generally salvaged by the following two methods:

1) Charge preheating.
2) Preheating of combustion air.

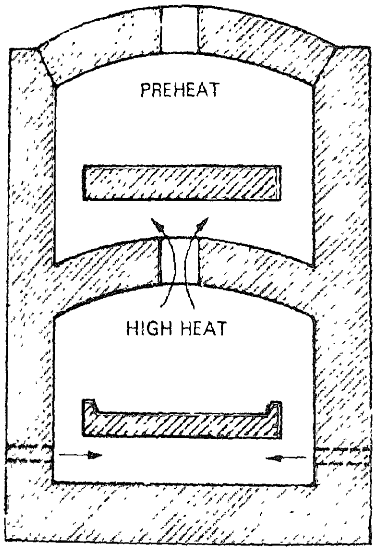
Besides, there are other recovery techniques such as steam generation through waste heat boilers, gas turbine systems, vapour absorption, refrigeration systems, etc. However,coverage on the above systems fall outside the perview of this booklet.

### Charge preheating

The direct recovery of energy from waste gases can be achieved in metallurgical furnaces by preheating the incoming raw materials. The effectiveness of charge preheating depend upon the physical and dimensional properties of the material being heated alongwith the handling methods employed.

A continuous furnace of pusher type can be so operated that it utilises the waste heat by preheating the stock. If the rate of heating is low, most of the heat is imparted to the stock at the hot end, and the products of combustion can preheat the slowly moving ingots.

A typical example of charge preheating with waste gases is a forging furnace for production of hand tools. This is explained schematically in Fig. 12.



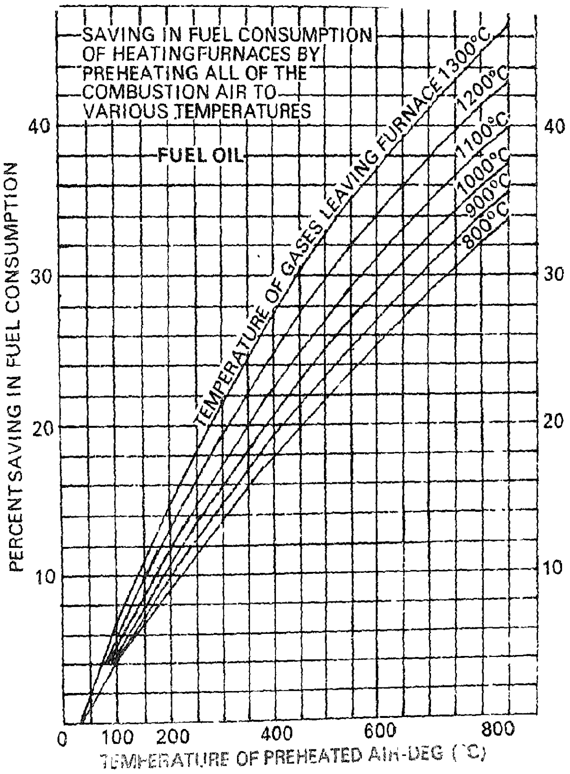
FURNACE WITH STOCK
PREHEAT CHAMBER ABOVE
(Fig 12)

### Preheating of combustion air

Considerable fuel savings can be affected by preheating the combustion air, and the heat saving devices used for this purpose, are the recuperator and the regenerator. The saving of fuel oil by preheating of air is shown in Fig. 13

### Advantages of hot combustion air

1. Saving in fuel consumption.
2. Increase in flame temperature.
3. Improvement in combustion.
4. Reduction in initial heating time.
5. Reduction in scale losses.



SAVING OF FUEL OIL BY
PREHEATING OF AIR
(Fig 13)

In a recuperator, heat exchange takes place between the flue gases and the air through metallic or ceramic walls. On the other hand, in a regenerator, the flue gases and the air to be heated are passed alternatively through a heat storing medium, thereby resulting in transfer of heat.

A comparison of the advantages of recuperator over a regenerator is shown below:

| | **Regenerator** | **Recuperator** |
|---|---|---|
| Requirement of size and space | Higher | Lower |
| Where used | Glass and Steel melting furnaces | Smaller engineering furnaces |
| Requirement of civil work | Large | Small |
| Initial installation and maintenance cost | High | Low |

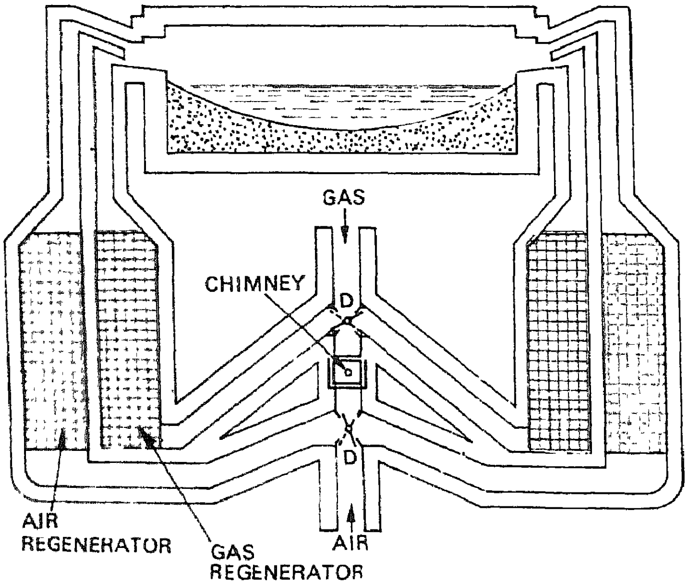
**Regenerators**

The regeneration which is preferable for large capacities has been very widely used in glass and steel melting furnaces. Important relations exist between size of the furnace (and regenerator), time between reversals, thickness of brick, conductivity of brick and heat storage ratio of the brick.

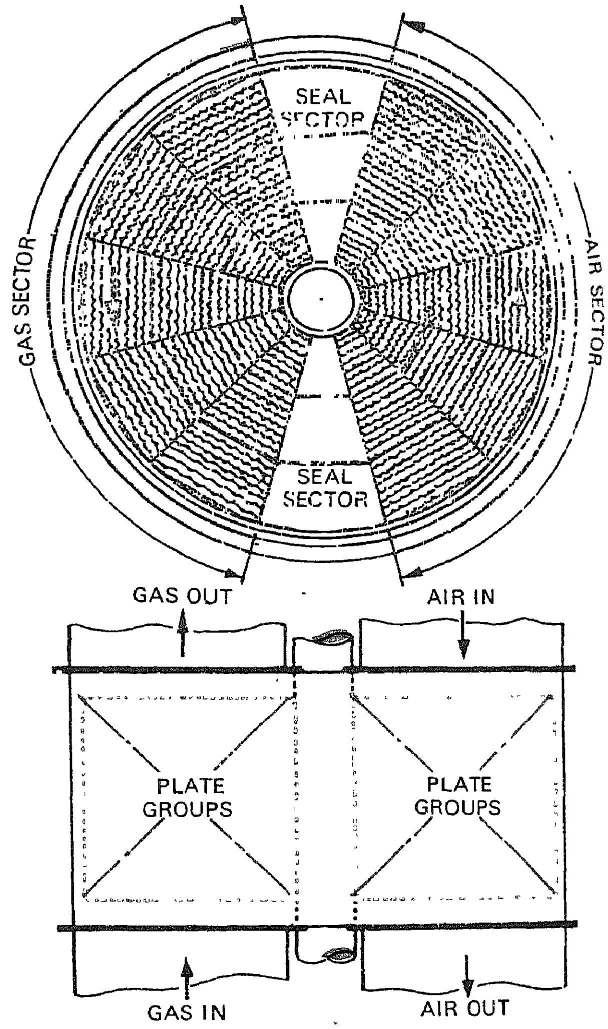
In the regenerators, the time between the reversals is an important aspect, long periods would mean higher thermal storage and hence larger regeneration and higher cost. Furthermore, long periods of reversal result in lower average temperature of preheat and consequently reduce fuel economy.

Accumulation of dust on the bricks and slagging of the brick surfaces, cause the efficiency of heat transfer in the regenerator to decrease as the furnace becomes old. Heat losses from the walls of the regenerator and leakage of air inwards during the gas period and out during the air period, also cause an apparent decrease in the heat transfer coefficient. Taking into effect all the above factors, the overall heat-transfer coefficient for checkers operating with natural draft can be taken as 4.0 to 6.5 Kcal/ $m^2$/hr/°C.

Besides, the checker brick work heat can be salvaged from flue gases by means of rotary regenerators. This device consists of multiples of slightly separated metal plates supported in a frame attached to a slowly moving rotor shaft, which is arranged edge on to the gas and air flow. As these plates pass progressively through the gas stream, they give up heat to the air before re-entering the hot gas stream, thus maintaining the regenerative cycle. Seals are provided to reduce air infiltration into the gas. Soot blowers are located in the assembly to remove soot and oil deposits periodically. The general principle of working is shown in Fig.14.



(Fig.14)– ILLUSTRATION OF A REGENERATIVE FURNACE



(Fig.14a) – REGENERATOR

**Recuperators**

A recuperator is a heat exchanger between the waste ga and the air to be pre-heated. It usually consists of a syste of ducts or tubes, some of which carry the air for combustion to be pre-heated, the others contain the sources of waste heat.

The recuperators may be of ceramic or metallic types. The ceramic recuperators are bulky and offer considerable resistance to transfer of heat because of low conductivity and also have a greater tendency for leakages. Metallic recuperators, however, are less prone to leaks and thermal expansions and can be controlled. Metallic recuperators are easier to maintain and install and involve less initial cost. Due to the above reasons, ceramic recuperators are not widely in use.

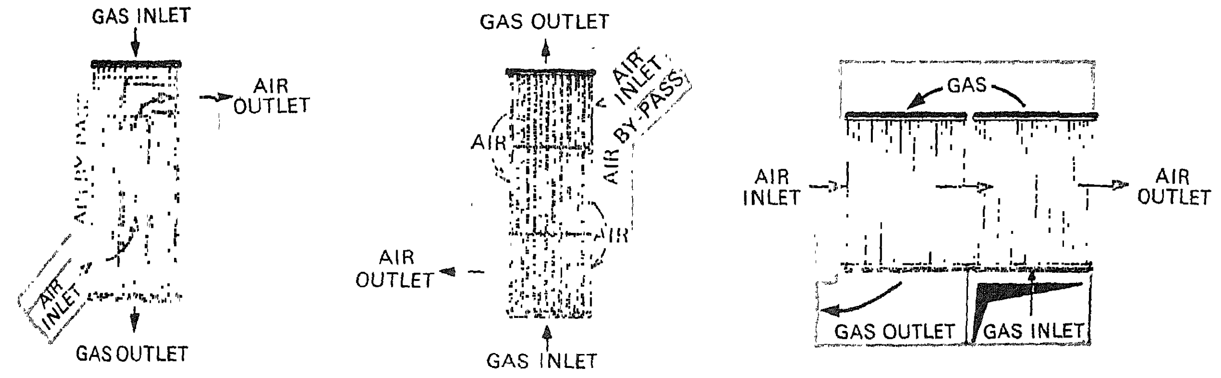
Some of the common flow arrangements encountered in recuperators are depicted in Figs. 15 and 16.

In a parallel flow recuperator, the air and hot gases flow in the same direction. In a counter flow recuperator, the direction of flow of hot gases is opposite to that of air. However, in a cross flow recuperator, the air and hot gases flow at right angles to each other.

The considerations for design and selection of a metallic recuperator must take into account

- waste gas temperature.
- desired air/fuel gas pre-heat.
- initial cost and maintenance cost.
- materials available for use in recuperator.
- operating pressure, on the fuel gas and combustion air side, as well as permissible pressure drops in the recuperator system.
- availability of space for installation of recuperator.
- campaign life of furnace and reliability desired in the system.

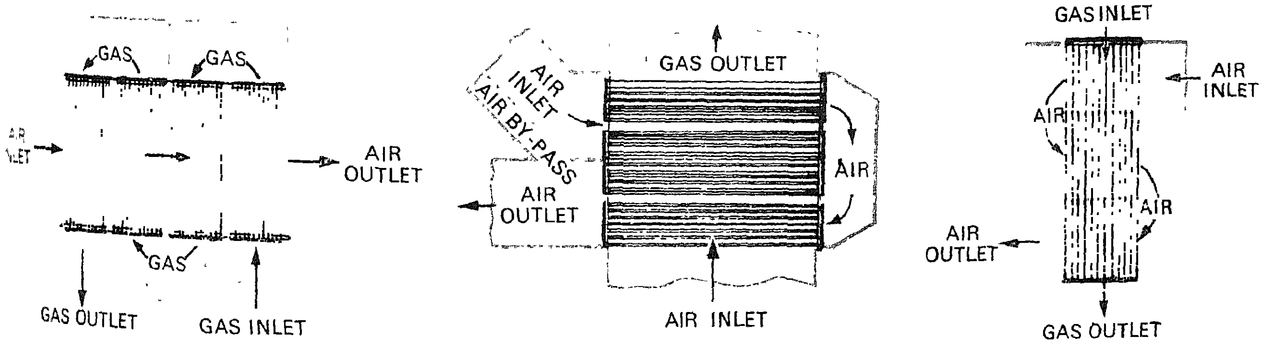
Metallic recuperators can be of three basic types depending on the method of heat transfer, viz., radiation, convection, combined convection and radiation type.



GAS DOWNFLOW
AIR AND GAS COUNTERFLOW
SINGLE PASS

GAS UPFLOW
AIR COUNTERFLOW,
THREE PASS

GAS UPFLOW AND DOWNFLOW
AIR COUNTERFLOW,
SINGLE PASS

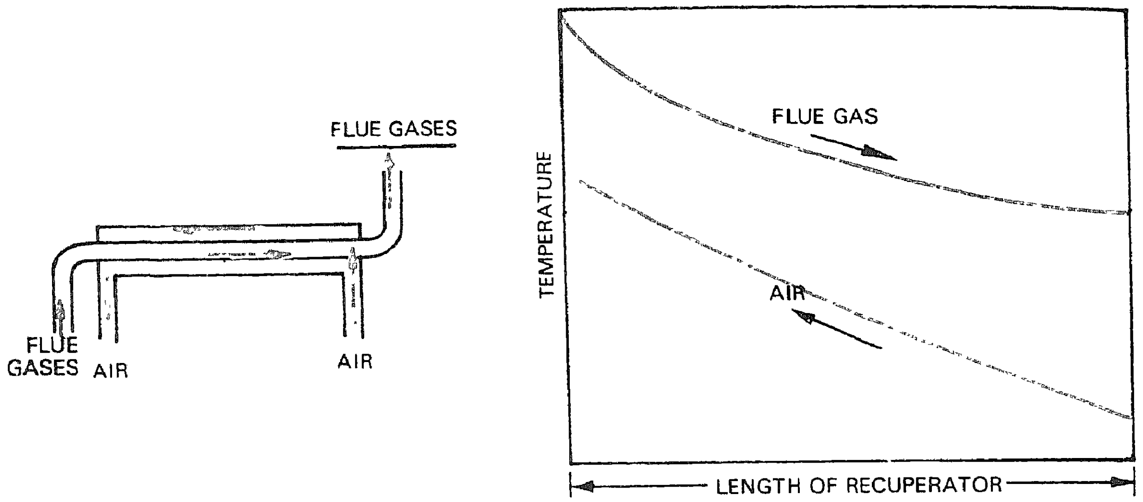


GAS UPFLOW AND DOWNFLOW
AIR COUNTERFLOW, SINGLE PASS

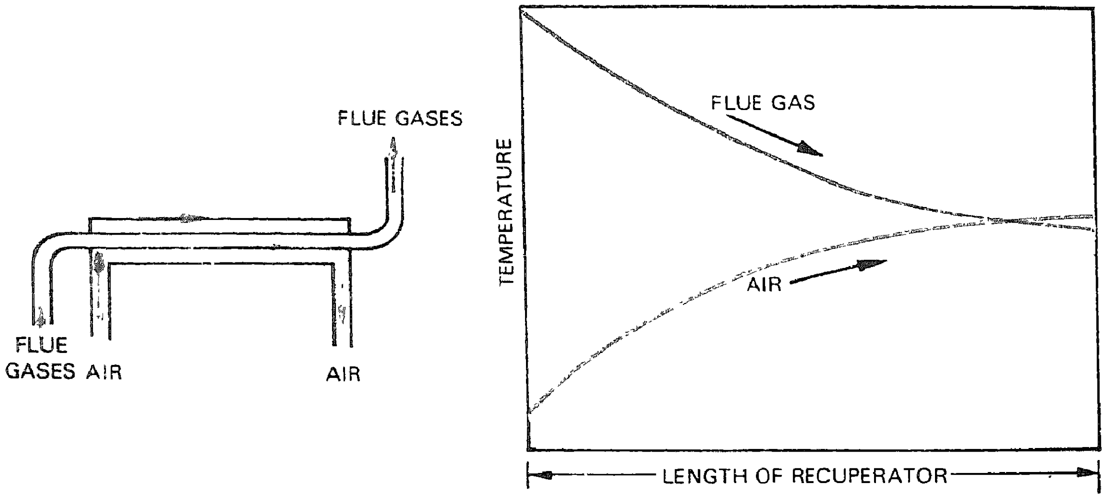
GAS UPFLOW
AIR COUNTERFLOW, TWO PASS

GAS DOWNFLOW
AIR PARALLEL FLOW, THREE PASS

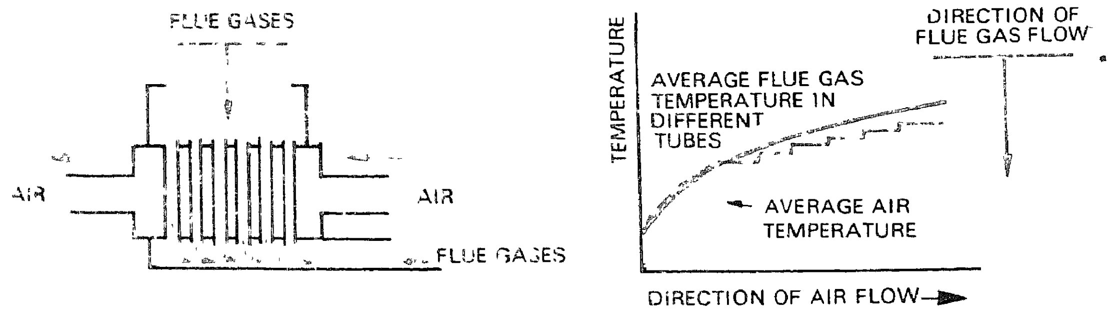
(Fig. 15)



COUNTER-FLOW RECUPERATOR AND TEMPERATURE DISTRIBUTION.



PARALLEL-FLOW RECUPERATOR AND TEMPERATURE DISTRIBUTION.

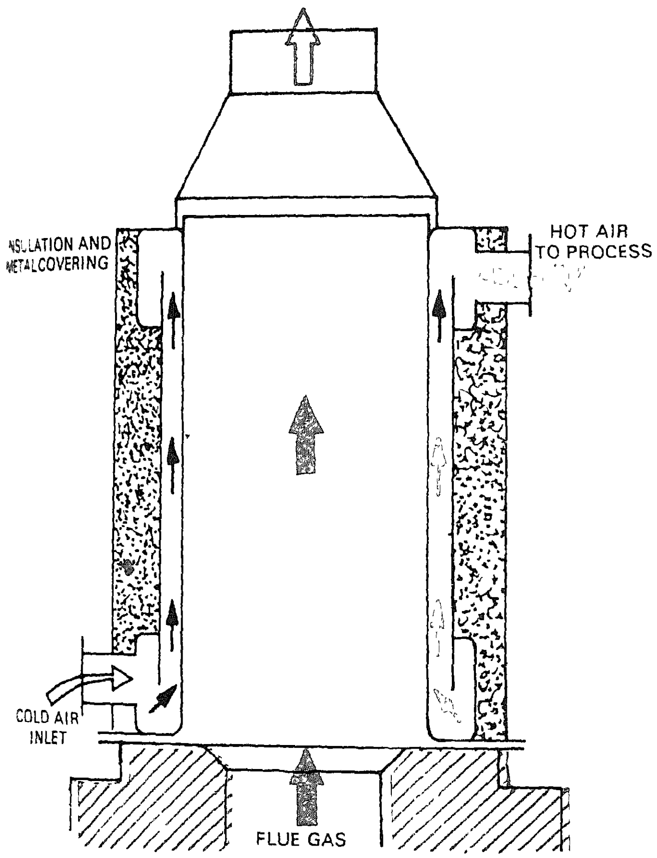


CROSS-FLOW RECUPERATOR AND TEMPERATURE DISTRIBUTION

(Fig 16) – TYPES OF FLOWS AND TEMPERATURE DISTRIBUTION

### Radiation recuperator

a radiation recuperator, the products of combustion enter the recuperator through an opening in the furnace roof while air flows at a higher velocity through a narrow annulus between the outer and inner walls. The outer shell is insulated. Fins are provided on the inner shell to increase the heat transfer area. This type of a simple recuperator is particularly suitable for small forging furnaces This is shown in Fig. 17



(Fig.17) – METALLIC RADIATION RECUPERATOR

Radiation recuperators can operate with waste gas temperatures in the range of 1000 to 1500°C to pre-heat air up to 600°C. The advantage of radiation recuperator over convection recuperator is that the heat transfer is intensive through radiation and also offers possibility of a higher air pre-heat. Other advantages are low pressure drop in flue gas side because of larger cross sections, thereby enhancing the possibility of using dust laden waste gases.

### Convection recuperator

These types of recuperators can be with a heating system made up of either drawn steel tubes, or cast tubes. Convection recuperators are used with flue gas temperatures from 300 to 1050°C; the degree of air preheat is limited to 600°C

### Combined radiation and convection recuperator

The advantages of radiation and convection recuperators are combined in the arrangement of heat exchanging surfaces. In this system, a tube bundle is arranged in a ring inside a double shell type recuperator.

A case study of a galvanizing furnace in a steel tube plant showed significant fuel savings on installation of a metallic recuperator as illustrated below:

System: heating of combustion air in a recuperator.

Average consumption of furnace oil in the furnace: 3000 litres/day (24 hrs.)

Temperature of flue gases before heat recovery: 580°C.

Temperature of flue gases after installation of recuperator at the exit: 400°C.

Temperature of combustion air at recuperator outlet: 320°C.

Quantity of air heated: 2000 N. Cubic Metres/hr.

Quantity of heat recycled back to the furnace by preheating of combustion air: 1,71,000 Kcal/hr.

Quantity of furnace oil saved per day: 500 litres/day (Rs. 1400/day)

Monthly saving in furnace oil: Rs. 42,000

Investment on the system: Rs. 1,05,000

Payback period on investment: 2½ months.

Quantitatively, **every 21°C rise in combustion air temperature results in one percent fuel oil savings.** However, the quantum of savings are normally greater with higher flame temperature, reduced excess air levels and higher productivity of the furnace.

### Failure of metallic recuperator

Some of the major sources of metallic recuperators and the possible remedies are discussed here below:

### Oxidation

Parts of the recuperator which reach temperatures of 500°C and above are subjected to oxidation by oxygen, water vapour or carbon dioxide present in waste gases. The intensity of attack depends on the temperature of surfaces as well as the concentration of oxidants in the gases. However, alloys are readily available today to counter oxidation up to a wall temperature of 1100°C. However, one must consider the fact that ultimately the recuperator will suffer scaling and will need replacement. Alloying elements in steel such as chromium, silicon, nickel are used to withstand high temperature services.

### Sulphur attack

The action of sulphur on the waste gases depends on the nature of gases (oxidising or reducing), temperature of gases, wall temperature and on the type of metal used as the heat exchanging surfaces. At the hot end of a recuperator with flue gases of oxidising nature, and the presence of vanadium oxides sulphur in the waste gases is corrosive. At the cooler end of recuperator, acid corrosion may occur due to the action of sulphur, if metal temperatures drop below the acid dew point of gases. Acid dew point for products of combustion depends mainly upon the sulphur content of the fuel and varies from 130°C with 1% sulphur to about 180°C with 4% sulphur in the fuel. The problem of low temperature corrosion is taken care of at the time of designing the recuperator, by ensuring that the wall temperature in all parts of the recuperator are well above the acid dew point of gases. This is done by choosing a suitable gas/air flow pattern and other changes in the constructional features of a recuperator.

### High temperature corrosion

High temperature corrosion means the corrosion attack on metallic surfaces in a certain temperature range caused through traces of vanadium contained in the fuel oil ash. The insoluble metal oxides in the fuel ash, viz., vanadium pentoxide and sodium oxide, cause considerable corrosion when the metal temperature is in the range of about 680°C. The hazards of high temperature corrosion is to be avoided by maintaining the metal wall temperature of a recuperator below 600°C. This limitation is not there in case of Ceramic Recuperator.

### Cracking and leakage in heat exchanging parts

This type of failure in a recuperator is due to the thermal expansion not being contained fully in different parts of the recuperator. Sometimes, this also occurs if the recuperator which is supposed to expand in a particular direction is restricted due to any shift or changes in the refractories housing the recuperator. This problem can be countered by paying considerable attention to thermal expansion in the metallic recuperator at the design stage.

REFERENCE:

1. Industrial Furnaces (Vol. I & II)—W. Trinks & M.H. Mawhinney, John-Wiley Publication.
2. Fuel Economy Hand Book—NIFES, London.
3. Industrial Energy Conservation—A Handbook for Engineers and Managers—D.A. Reay, Pergamon Press Ltd.

**This booklet is one of a series on fuel oil conservation, others in the series are listed below:**

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2) Efficient generation of steam.
3) Efficient utilisation of steam.
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5) Refractories.
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# 6

# Refractories

# Introduction

Manufacturing processes involving high temperatures whether melting, refining, sintering, heating, and soaking or heat treatment, need refractories to withstand service conditions at the desired operating temperatures. Use of the right type of refractories in furnaces and kilns, increase their efficiency and result in substantial fuel savings.

This booklet covers the types of refractories, their properties and applications, and how they may be applied to give better fuel efficiency and service life.

# What is a refractory?

Any material can be described as 'refractory,' if it can withstand the action of abrasive or corrosive solids, liquids or gases at high temperatures.

The various combinations of conditions in which refractories are used, make it necessary to manufacture a range of refractory materials with different properties. Refractory materials are made in varying combinations and shapes and for different applications.

### Requirements of refractories

The general requirements of a refractory material can be summed up as:

- Its ability to withstand high temperatures.
- Its ability to withstand sudden changes of temperatures.
- Its ability to withstand action of molten metal slag, glass, hot gases, etc.
- Its ability to withstand load at service conditions.
- Its ability to withstand load and abrasive forces.
- Low coefficient of thermal expansion.
- Should be able to conserve heat.
- Should not contaminate the material with which it comes into contact.

# Properties of refractories

Some of the important properties of refractories are:

**Melting point:** Pure substances melt sharply at a definite temperature. Most refractory materials consist of high melting particles bonded together. At high temperature, glass fuses and as the temperature rises, the resulting slag increases in quantity by partial solution of the refractory particles. The temperature at which this action results in failure of a test pyramid (cone) to support its own weight is called, for convenience, the melting point of the refractory. Table 1 shows the melting point of some pure compounds used as refractories.

### Table-I
### Melting points of pure compounds

| Pure compound | Formula | Melting temperature °C |
|---|---|---|
| Alumina | $Al_2O_3$ | 2050 |
| Lime | $CaO$ | 2570 |
| Chromite | $FeOCr_2O_3$ | 2180 |
| Chromium Oxide | $Cr_2O_3$ | 2275 |
| Magnesia | $MgO$ | 2800 |
| Silica | $SiO_2$ | 1715 |
| Titania | $TiO_2$ | 1850 |

**Size:** The size and shape of the refractories is a part of the design feature. It is an important feature in design since it affects the stability of any structure. Accuracy and size is extremely important to enable proper fitting of the refractory shape and to minimise the thickness and joints in construction.

**Bulk density:** A useful property for refractories is bulk density, which defines the material present in a given volume. An increase in bulk density of a given refractory increases its volume stability, its heat capacity, as well as *resistance to slag penetration.*

**Porosity:** The apparent porosity is a measure of the volume of the open pores, into which a liquid can penetrate, as a percentage of the total volume. This is an important property in cases where the refractory is in contact with molten charge and slags. A low apparent porosity is desirable since it would prevent easy penetration of the refractory size and continuity of pores will have important influences on refractory behaviour. A large number of smal pores is generally preferable to an equivalent number of large pores. However, a measure of the true porosity whic also takes into account the volume of closed pores, gives a reasonable idea of the texture of the material, as well as sintering characteristics. In fact, porosity, bulk density and apparent solid density have been termed rightly as "Vital statistics" of refractory shapes.

**Cold crushing strength:** The cold crushing strength, which is considered by some to be of doubtful relevance as a useful property, other than that it reveals little more than th ability to withstand the rigours of transport, can be used as useful indicator to the adequacy of firing and abrasion resistance in consonance with other properties such as bulk density and porosity.

**Pyrometric cone equivalent**: Temperature at which a refractory will deform under its own weight is known as its softening temperature which is indicated by PCE. Refractories, due to their chemical complexity, melt progressively over a range of temperature. Hence refractoriness or fusion point is ideally assessed by the cone fusion method. The equivalent standard cone which melts to the same extent as the test cone is known as the pyrometric cone equivalent. Thus in Fig. 1, refractoriness of Sample A is much higher than B and C.

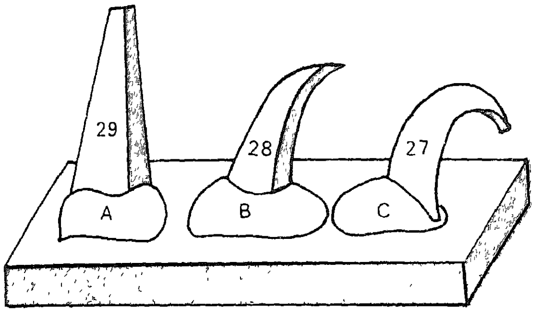


Fig. 1–PYROMETRIC CONES

The pyrometric cone equivalent indicates only the softening temperature. But, in service the refractory is subjected to load which would deform the refractory at a much lower temperature than that indicated by PCE. With change in the environmental conditions, such as reducing atmosphere, the P.C.E. value changes drastically.

**Refractoriness under load**: The refractoriness under load test (RUL test) gives an indication of the temperature at which the bricks will collapse, in service conditions with similar load.

However, under actual service where the bricks are heated only on one face, most of the load is carried by the relatively cooler rigid portion of the bricks. Hence the RUL test gives only an index of the refractory quality, rather than a figure which can be used in a refractory design. Under service conditions, where the refractory used is heated from all sides such as checkers, partitioin walls, etc. the RUL test data is quite significant.

**Creep at high temperature**: Creep is a **time dependent** property which determines the deformation in a given time and at a given temperature by a material under stress. The criterion of acceptance usually adopted is; that compressive creep under the required conditions of load and temperature shall not exceed 0.3% in the first 50 hours of the test. This figure has been found to indicate that the creep rate falls by a negligible amount at the end of the stipulated period, and therefore the refractory can be considered safe to use for a much longer time.

**Volume stability, expansion, and shrinkage at high temperatures**: The contraction or expansion of the refractories can take place during service. Such permanent changes in dimensions may be due to:

i) The changes in the allotropic forms which cause a change in specific gravity.
ii) A chemical reaction which produces a new material of altered specific gravity.
iii) The formation of liquid phase.
iv) Sintering reactions.
v) It may also happen on account of fluxing with dust and slag or by the action of alkalies on fireclay refractories, to form alkali-alumina silicates, causing expansion and disruption. This is an example which is generally observed in blast furnaces

While it is desirable that all these changes are effected during manufacturing, it is not possible due to economic reasons, as the process is time dependent. Permanent Linear Change (PLC) on reheating and cooling of the bricks give an indication on the volume stability of the product as well as the adequacy of the processing parameters during manufacture. It is particularly significant as a measure of the degree of conversion achieved in the manufacture of silica bricks.

**Reversible thermal expansion**: Any material when heated, expands, and contracts on cooling. The reversible thermal expansion is a reflection on the phase transformations that occur during heating and cooling. The PLC and the reversible thermal expansion are followed in the design of refractory linings for provision of expansion joints.
As a general rule, those with a lower thermal expansion co-efficient are less susceptible to thermal spalling.

**Thermal conductivity**: Thermal conductivity depends upon the chemical and mineralogical compositions as well as the glassy phase contained in the refractory and the application temperature. Although it is one of the least important properties as far as service performance is concerned, it evidently determines the thickness of brick work.

The conductivity usually changes with rise in temperature. In cases where heat transfer is required through the brick work, for example in recuperators, regenerators, muffles, etc. the refractory should have high conductivity. Low thermal conductivity is desirable for conservation of heat by providing adequate insulation.

The provisions for back-up insulation, conserves heat but at the same time it increases the hot face temperature and hence the demand on the refractory quality increases. Accordingly, insulation on the roof in open hearth furnaces is normally not provided, otherwise it would cause failure due to severe dripping. Depending on the characteristic of the refractory used in the hot face, such as the high temperature load bearing capacity, it may be required that the quality of the brick be increased to the rise in temperature caused by over insulation.

Light weight refractories of low thermal conductivity find wider applications in the moderately low temperature heat treatment furnaces, where its primary function is usually conservation of energy. It is more so in case of batch type furnaces where the low heat capacity of the refractory structure would minimise the heat storage during the intermittent heating and cooling cycles.

## Classification of refractories

Refractories can be classified on the basis of chemical composition and use and methods of manufacture as shown below:

| | **Examples** |
|---|---|
| **Classification based on Chemical composition** | |
| ACID—which readily combines with bases. | Silica, Semisilica, Alumino-silicate. |
| BASIC—which consists mainly of metallic oxides which resists the action of bases. | Magnesite, Chrome-magnesite, Dolomite. |
| NEUTRAL—which doesn't combine; neither with acids nor bases. | Chrome, Pure, Alumina. |
| Special | Carbon, Silicon Carbide, Zirconia. |
| **Classification based on end use** | Blast Furnace<br>Casting Pit |
| **Classification based on method of manufacture** | —Dry Press Process<br>—Fused Cast<br>—Hand Moulded<br>—Formed (Normal, fired or (chemically bonded.)<br>—Unformed (Monolithics—plastics, Ramming Mass, Gunning, Castable, Spraying.) |

Some of the typical refractories in industrial use are as under:

**Fireclay refractories**

Fireclay refractories, such as firebricks, siliceous fireclays and aluminous clay refractories consist of aluminus silicates with various amounts of silica adding up $SiO_2$ content of less than 78% and containing less than 44% of $Al_2O_3$.

Table 2 shows that as the quantity of impurities increases and the amount of $Al_2O_3$ decreases, the melting point of fireclay brick decreases. Owing to its relative cheapness and widespread location of the raw materials used to manufacture firebricks, this material finds uses in most furnaces, kilns, stoves, etc.

### Table-II
### Properties of typical fireclay bricks

| Brick | Percent $SiO_2$ | Percent $Al_2O_3$ | Other Constituents | PCE °C |
|---|---|---|---|---|
| Super Duty | 49-53 | 40-44 | 5-7 | 1745-1760 |
| High Duty | 50-80 | 35-40 | 5-9 | 1690-1745 |
| Intermediate | 60-70 | 26-36 | 5-9 | 1640-1680 |
| High Duty (Siliceous) | 65-80 | 18-30 | 3-8 | 1620-1680 |
| Low Duty | 60-70 | 23-33 | 6-10 | 1520-1595 |

Firebrick is the most common form of refractory material. It is used extensively in the iron and steel industry, non-ferrous metallurgy, glass industry, pottery kilns, cement industry, and by many others.

### High alumina refractories

Alumino silicate refractories containing more than 45% alumina are generally termed as high alumina materials. The alumina concentration ranges from 45 to 100%. The refractoriness of high alumina refractories increases with increase in alumina percentage. The applications of high alumina refractories includes the hearth and shaft of blast furnaces, ceramic kilns, cement kilns, glass tanks and crucibles for melting a wide range of metals.

### Silica brick

Silica brick (or Dinas) is a refractory material containing at least 93% $SiO_2$. The raw material is quality rocks. Various grades of silica brick have found extensive use in the iron and steel melting furnaces. In addition to high fusion point mulite type refractories, the other important properties are their high resistance to thermal shock (spalling) and their high refractoriness. It finds typical use in glass making and steel industry.

The outstanding property of silica brick is that it does not begin to soften under high loads until its fusion point is approached. This behaviour contrasts with that of many other refractories, for example alumino silicate materials, which begin to fuse and creep at temperatures considerably lower than their fusion points. Other advantages are flux and slag resistance, volume stability and high spalling resistance.

### Magnesite

Magnestite refractories are chemically basic materials, containing at least 85% magnesium oxide. They are made from naturally occuring magnesite ($MgCO_3$).

The properties of magnesite refractories depend on the concentration of silicate bond at the operating temperatures. Good quality magnesite usually results from a CaO-$SiO_2$ ratio of less than 2 with a minimum ferrite concentration, particularly if the furnaces lined with the refractory operate in oxidizing and reducing conditions. The slag resistance is very high particularly to lime and iron rich slags.

### Chromite refractories

Here, a distinction must be made between chrome-magnesite refractories and magnesite-chromie-refractories. Chrome-magnesite material usually contain 15-35% $Cr_2O_3$ and 42-50% MgO whereas magnesite-chromite refractories contain at least 60% MgO and 8-18% $Cr_2O_3$.

Chrome-magnesite refractories are made in a wide range of qualities and are used for building the critical parts of high temperature furnaces. These materials can withstand corrosive slags and gases and have high refractoriness. The magnesite-chromite products are suitable for service at the highest temperatures and in contact with the most basic slags used in steel melting. Magnesite-chromite usually has a better spalling resistance than chrome-magnesite.

### Zirconia refractories

Zirconium dioxide ($ZrO_2$) is a polymorphic, material. There are certain difficulties in its usage and fabrication as a refractory material. It is essential to stabilise it before application as a refractory. This is achieved by incorporating small quantities of calcium, magnesium and cerium oxide, etc. Its properties depend mainly on the degree of stabilisation and quantity of stabiliser as well as the quality of the original raw material. Zirconia refractories have a very high strength at room temperature which is maintained upto temperatures as high as 1500°C. They are, therefore, useful as high temperature constructional materials for furnaces and kilns. The thermal conductivity of zirconium dioxide is found to be much lower than that of most other refractories and the material is therefore used as a high temperature insulating refractory.

Since Zirconia exhibits very low thermal losses and does not react readily with liquid metals, it is particularly useful for making refractory crucibles and other vessels for metallurgical purposes. Zirconia is a useful refractory material for glass furnaces primarily since it is not easily wetted by molten glasses and because of its low reaction with them.

### Oxide refractories (Alumina)

Alumina refractory materials which consist of aluminium oxide with little traces of impurities are often known as pure alumina.

Alumina is one of the most chemically stable oxides known. It is mechanically very strong, insoluble in water and super heated steam, and in most inorganic acids and alkalies. Its properties make it suitable for the shaping of crucibles for fusing sodium carbonate, sodium hydroxide and sodium peroxide. It has a high resistance in oxidising and reducing atmosphere. Alumina is extensively used in heat processing industries. Highly porous alumina is used for lining furnaces operating up to 1850°C.

## Monolithics

Monolithic refractories are replacing the conventional type fired refractories at a much faster rate in many applications including those of industrial furnaces. The main advantages being:

- i) It eliminates joints whcih is an inherent weakness.
- ii) Method of application is faster and skilled measures in large number are not required.
- iii) Transportation and handling are simple.
- iv) Offers better scope to reduce downtime for repairs.
- v) Offers considerable scope to reduce inventory and eliminate special shapes.
- vi) It is a heat saver.
- vii) Has better spalling resistance.
- viii) Has greater volume stability.

Various means are employed in the placement of monolithics like ramming casting, gunniting, spraying, sand slinging, etc. Ramming masses are used mostly in cold applications where proper consolidation of the material is important. The same practice can be adopted with both air setting and heat setting materials. Proper ramming tools need to be selected.

Castables by name implies a material of hydraulic setting in nature. Calcium aluminate cement being the binder, it will have to be stored properly to prevent moisture absorption. Further its strength starts deteriorating after a period of 6 to 12 months.

## Insulating materials

Insulating materials greatly reduce the heat losses through walls. Insulation is effected by providing a layer of material having a low heat conductivity between the internal hot surface of a furnace and the external surface, thus causing the temperature of the external surface reduced.

Insulating materials owe their low conductivity to their pores while their heat capacity depends on the bulk density and specific heat. Structure of air insulating material consists of minute pores filled with air which have in themselves very low thermal conductivity, excessive heat affects all insulation material adversely, but the temperatures to which the various materials can be heated before this adverse effect occurs differ widely. Clearly, therefore, the choice of an insulating material must depend upon its effectiveness to resist heat conductivity and upon the temperature that it will withstand.

One of the most widely used insulating material is diatomite, also known as kiesel guhr which is made up from a mass of skeletons of minute aquatic plants deposited thousands of years ago on the beds of seas and lakes. Chemically this consists of silica contaminated with clay and organic matter. A wide range of insulating refractories with wide combinations of properties are now available. The important physical properties of some insulating refractories are shown in the table below:

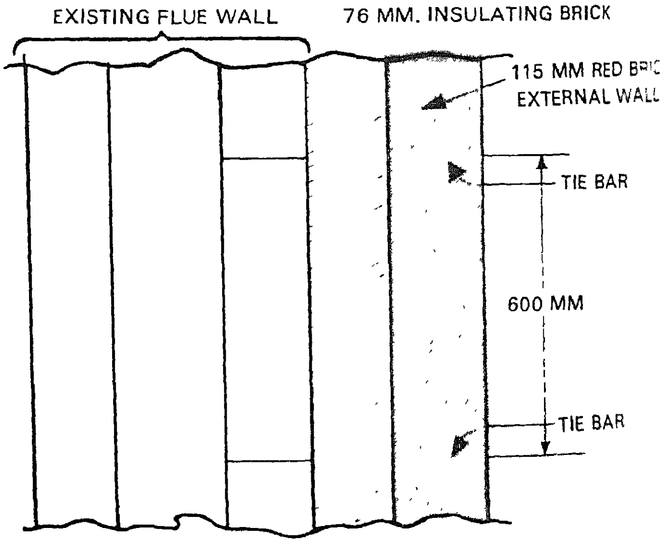
**Table-III**

| Type | Thermal conductivity at 400 C mean Kcal/m/ C | Max. safe temperature C | Cold Crushing Strength Kg/cm² | Porosity % | Bulk density Kg/m |
|---|---|---|---|---|---|
| Diatomite Solid Grade | 025 | 1000 | 270 | 52 | 1090 |
| Diatomite Porous Grade | .014 | 800 | 110 | 77 | 540 |
| Clay | 030 | 1500 | 260 | 68 | 560 |
| High Aluminia | .028 | 1500-1600 | 300 | 66 | 910 |
| Silica | .040 | 1400 | 400 | 65 | 830 |

## Attaching insulation

The method of attaching insulation bricks is illustrated in Fig 2

**METHOD OF ATTACHING INSULATION TO AN EXISTING FLUE WALL**



(Fig.2) — ELEVATION

In Fig.2, a 115mm brick wall is built outside the existing one, leaving a suitable gap of 76mm between the old and new walls into which the insulating brick may be inserted as the wall is being built.

To keep the wall rigid, it is necessary to incorporate one or two buttresses and further strengthening is possible with a number of T bars about 600 mm apart.

## Ceramic Fibres

Ceramic fibres are yet another class of material of recent origin. Ceramic fibre which are manufactured by blowing either a high velocity gas or high velocity gases on to a molten stream of alumino-silicate material with a controlled composition that takes care of devitrification and shrinkage. The resulting fluffy, white cotton like fibre can be spun and fabricated into textiles, blankets, felts, boards, blocks, etc.

These products have low thermal conductivity, very low heat storage, extremely light weight, immunity to thermal shocks, and are chemically stable as well as neutral exceptionally resistance to wetting by non-ferrous metals like aluminium, zinc and their alloys. Ceramic fibres are composed of high purity silica in various percentages. A 52-48 combination can be applied as a hot face insulation material up to 1420°C. Whereas a 62-38 combination imparts greater refractoriness to the fibre, 42% $Al_2O_3$, 52% $SiO_2$ and 6% $ZrO_2$ produces extra long staple fibre of 10 inches or so and are used for manufacturing ceramic fibre textiles and ropes.

The advantages of ceramic modules are:

i) Better fuel economy (Savings as high as 60% are feasible in the case of certain intermittent furnaces )
ii) Higher productive capacity of furnaces, due to reduced heat storage capacity.
iii) Higher service life of the furnace and reduced maintenance costs due to longer refractory life.
iv) Ease of installation.

## Selection of refractories

The selection of refractories for any particular application is made with a view to achieve the best performance of the equipment furnace, kiln or boiler and depends on certain properties of the refractories. Further, the choice of a refractory material for a given application will be determined by the type of furnace or heating unit and the prevailing conditions e.g. the gaseous atmosphere, the presence of slags, the type metal charge etc. It is, therefore, clear that temperature is by no means the only criterion for selection of refractories.

Any furnace designer or industry should have a clear idea about the service conditions which the refractory is required to face. The furnace manufacturers or users have to consider the following points, before selecting a refractory.

i) Area of application.
ii) Working temperatures.
iii) Extent of abrasion and impact.
iv) Structural load of the furnace.
v) Stress due to temperature gradient in the structures and temperature fluctuations.
vi) Chemical compatibility to the furnace environment.
vii) Heat transfer and fuel conservation.
viii) Cost considerations.

It is therefore, essential to have an objective evaluation of the above conditions. The proper assessment of the desired properties would provide guidelines for selection of the proper refractory materials.

It would be important to mention here that the furnace manufacturer or a user is also concerned with the conservation of energy. Fuel can be saved in two ways: either by insulation or by faster working. Both these methods give low energy cost per tonne of product.

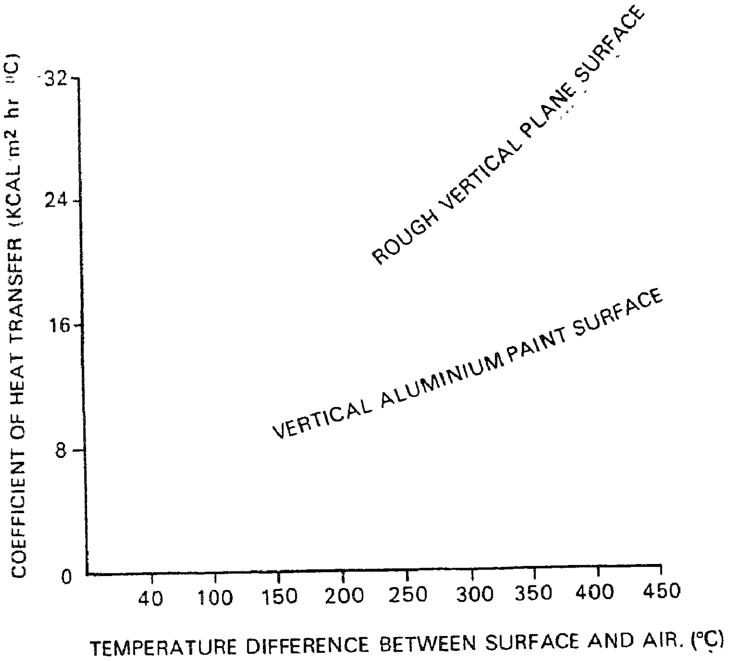
## Heat losses from furnace walls

In furnaces and kilns, heat losses from furnace walls, affect the fuel economy substantially. The extent of wall losses depends on:

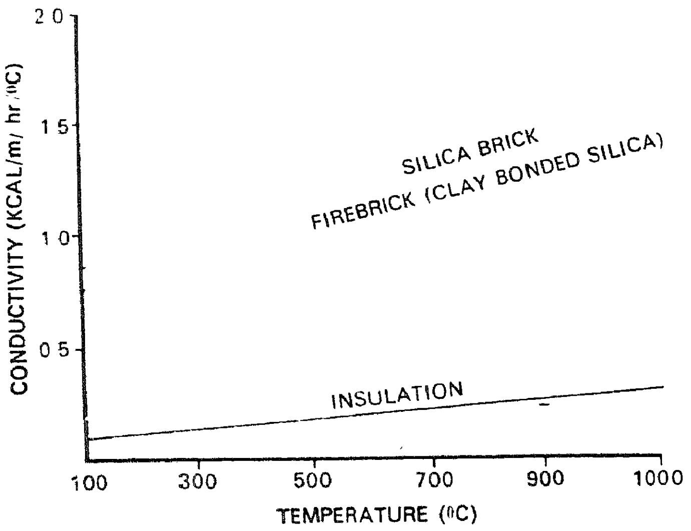
i) emissivity of walls;
ii) conductivity of refractories;
iii) wall thickness;
iv) whether furnace or kiln is operated continuously or intermittently.

Different materials have different radiation power (emissivity). Thus emissivity of walls coated with aluminium paint is lower than that of bricks Fig.3 shows the coefficient of heat dissipation for the following conditions:

a) rough vertical plane surface.
b) vertical aluminium painted walls.



(Fig 3)— COEFFICIENT OF HEAT TRANSFER FOR DIFFERENT CONDITIONS IN STILL AIR AT 40 C.

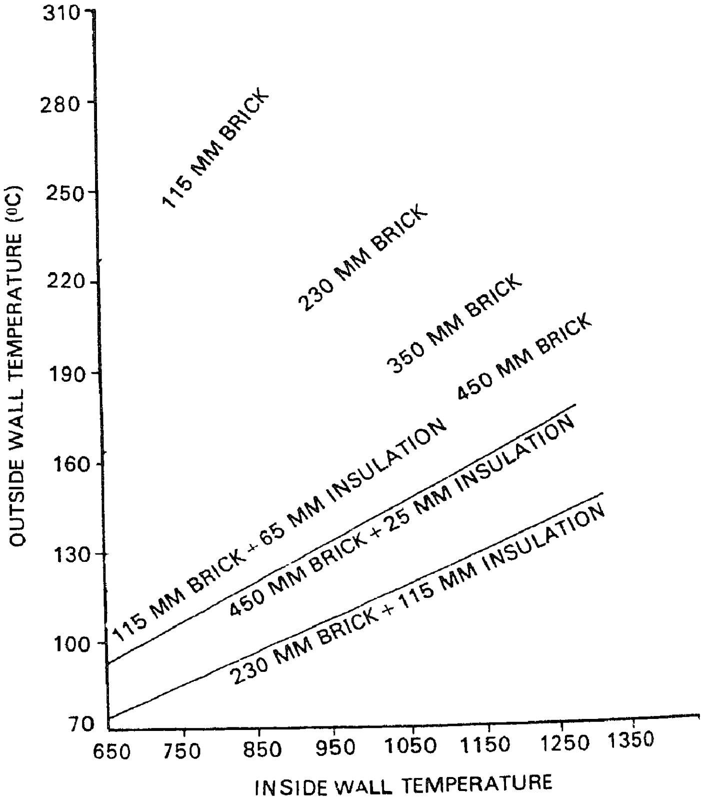


(Fig 4) AVERAGE CONDUCTIVITY OF REFRACTORY MATERIAL

The variations of thermal conductivity for typical refractory materials (silica brick, fireclay brick and insulation brick) with temperature is depicted in Fig.5. Thus at a mean temperature of 600°C, conductivity of the insulation brick is only 20 per cent of that for fireclay brick.

Heat losses can be reduced by increasing the wall thickness, or through the application of insulating bricks. Outside wall temperature and heat losses for a composite wall of a certain thickness of firebrick and insulation brick are much lower due to lesser conductivity of insulating brick as compared to a refractory brick. This is depicted by the curves in Figs.5 and 6. Thus heat losses from a furnace wall 115 mm thick at 650°C amounting to 2650 Kcal/m²/hr. can be cut down to 850 Kcal/m²/hr. by using 65 mm insulation on a 115 mm. wall.

The heat losses discussed in the preceding section are those incurred during steady, uninterrupted operation. In actual practice, operating periods ("on") alternate with idle



(Fig.5)— TEMPERATURE RELATION OF FACES FURNACE WALL.

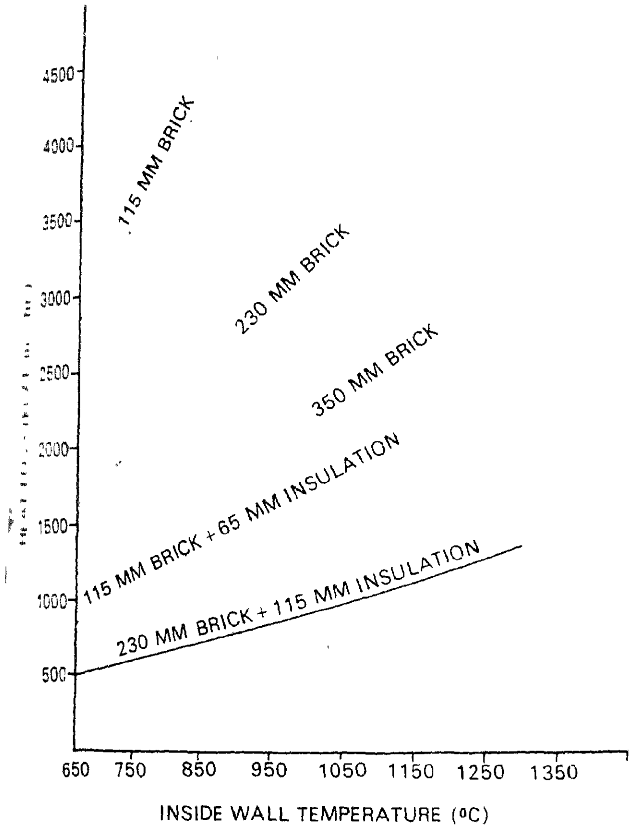


Fig 6—HEAT LOSSES THROUGH FURNACE WALLS

periods ("off"). During the off period, the heat stored in the refractories in the on-period is gradually dissipated, mainly through radiation and convection from the cold face. In addition, some heat is abstracted by air flowing through the furnace. Dissipation of stored heat is a loss, because the lost heat is at least in part again imparted to the refractories during the next "on" period, thus expending fuel to generate the heat. If a furnace is operated 24 hr. every third day, practically all of the heat stored in the refractories is lost. But if the furnace is operated 8 hrs. per day, not all the heat stored in the refractories is dissipated. For a furnace with firebrick wall (350 mm) it is estimated that 55 per cent of the heat stored in the refractories is dissipated from the cold surface during 16 hours idle period. Furnace walls built of insulating refractories and encased in a shell reduce flow of heat to the surroundings. The loss can further be reduced by inserting a fibre block between the insulating refractory and the steel casing. The general question one asks is how much heat loss can be reduced by application of insulation. The answer is that it depends on the thickness of firebricks and of the insulation and on continuity of furnace operation. The heat saving pattern with three of these variables are indicated in the table below:

## Table-IV
## Reduction of wall losses by insulation percent

| Thickness of Fire-brick wall mm | Continuous Operation Insulation 65mm | Continuous Operation Insulation 120mm | 1 Week Cycle Insulation 65mm | 1 Day Cycle 6 Days per week Insulation 65mm |
|---|---|---|---|---|
| 115 | 62 | 76 | 58 | 25 |
| 230 | 46 | 65 | 36 | 18 |
| 350 | 38 | 65 | 20 | 14 |
| 460 | 35 | 53 | 15 | 12 |

In the table, one week cycle means continuous operation for 6 days of 24 hrs. For 5 days operation, the savings reduced, approximately 10%, to one day cycle means 8 to 10 hr. per day. The tabular values must be reduced somewhat, if the wall is thick in comparison with the interior dimensions of the furnace. The tabular values apply only to those furnaces which are covered entirely with insulation, even under the binding.

**To sum up, the heat losses from the walls depend on**

1) Inside temperature.
2) Outside air temperature.
3) Outside air velocity.
4) Configuration of walls.
5) Emissivity of walls.
6) Thickness of walls.
7) Conductivity of walls.

The last two can be easily controlled by the furnace fabricator. The following conclusions can be drawn:

i) As the wall thickness increases, the heat losses reduce.
ii) As thickness of insulation is increased, heat losses reduce.
iii) The effect of insulation in reducing heat losses is more pronounced than the increase of wall thickness.
    Roughly 1 cm. of insulation brick is equivalent to 5 to 8 cm of refractory (firebrick).
iv) In intermittent furnaces, thin walls of insulating refractories are preferable to thick walls of a normal

refractory for intermittent operation since less heat is stored in them.

v) One approach to achieve less heat storage capacity would be to utilise insulating material itself to form the inner refractory lining. Robust refractories with fairly good strength and spalling resistance can be used for temperatures in the range of 1300°C. They are termed as hot face insulation.

vi) Hot face insulating bricks are lighter than normal refractories, weighing only one-third to one-half as much. Therefore, heat storage in the hot face insulation is very much reduced.

**Example: A case on thermal insulation of an oil fired forging furnace**

An oil fired furnace with 3.34 sq. metre hearth area and 350 mm thick side walls of fire bricks (IS6) is operated for about 8 hours a day. The furnace takes about one hr. in the morning to attain the desired furnace temperature of 1250 C. Moreover, the radiation losses are considerable. With a view to cut down the radiation loss and the heat storage or initial heating time of the furnace, it is desired to employ insulation.

The seven proposals of employing various refractories and insulating bricks of various thickness, have been studied from fuel savings considerations. The replacement of refractories at the roof and the doors' side is not being considered.

1: 450mm Firebrick.
2: 350mm Firebrick (the existing one)
3: 350mm Firebrick + 115mm Cold face insulation.
4: 230mm Firebrick + 115mm Hot face + 75mm Cold face insulation.
5: 230mm Firebrick + 115mm Hot face insulation.
6: 350mm Hot face insulation
7: 350mm Hot face insulation + 75mm Cold face insulation.

The various heat aspects are given in Tables, V and VI. The calculations and figures given in the tables are on the following basis:

**BASIS**

1) Furnace Dimensions
   earth = 1.83 M × 1.83 M
   Side wall internal height up to the lower end of arch = 60 mm wall thickness
   = 350 mm Firebrick (IS 6).
2) For convenience only three side walls have been taken into consideration for calculating radiation loss and initial heating time.
3) Initial heating time for Proposal 2 (existing one) is 1 hr For other proposals, the initial heating time has been calculated on the basis of relative mass of the refractory with respect to the mass associated with that of Proposal 2.
4) The furnace operates for 8 hrs.
5) Steady state internal furnace temperature is 1250 C.
6) Brick size = 230 mm × 115 mm × 75 mm.
7) Burner output at initial heating = 100 litres/hr
   Burner output at other times = 80 litres/hr. (Average)
8) i. Density of Firebrick (F.B ) = 1920 kg/m$^3$.
   ii. Density of Hot face insulation brick = (Hot face). 960 kg/m$^3$
   iii. Density of Cold face insulation brick = (Cold face 480 kg/m$^3$
9) Coefficient of conductivity in $\frac{\text{Kcal}}{\text{hr. m C}}$ of
   i. Fire Brick = 1.30
   ii. Hot Face Insulation = 0.414
   iii. Cold Face Insulation = 0.207
10) Price of furnace oil: Rs. 2.50/litre
11) Calorific value of furnace oil = 10300 Kcal/kg.
12) The bricks employed in various proposals can withstand the interfacial temperature obtained in actual operation of the furnace.
13) Percentage heat utilised in the heating of the material and refractories = 50%, i.e. of every 100 Kcal by oil, 50 Kcals are carried away to stack and 50 Kcals are available for raising temperature of furnace and materials.

Table-V

## Details of furnace walls and heat losses

| Proposal No. | Wall thickness | No. of bricks used | Corresp. mass of refractories. kg | Radiation losses Kcal/hr/m$^2$ | Total radiation in 8 hr. operation in Kcal. | Initial heating to attain the furnace temp. in minutes |
|---|---|---|---|---|---|---|
| 1) | 450mm Firebrick | 900 | 3430 | 2390 | $10.71 \times 10^4$ | 83 |
| 2) | 350mm Firebrick | 650 | 2482 | 3040 | $12.73 \times 10^4$ | 60 |
| 3) | 350mm Firebrick<br>+115mm Cold Face | 650<br>250 | 2720 | 1085 | $4.85 \times 10^4$ | 66 |
| 4) | 230mm Firebrick<br>+115mm Hot Face<br>+75 mm Cold Face | 450<br>250 | 2350 | 1085 | $4.75 \times 10^4$ | 57 |
| 5) | 230mm Firebrick<br>+115mm Hot Face | 450<br>250 | 2150 | 1845 | $7.73 \times 10^4$ | 52 |
| 6) | 350mm Hot Face | 650 | 1240 | 1085 | $4.55 \times 10^4$ | 30 |
| 7) | 350mm Hot Face<br>+75mm Cold Face | 650<br>164 | 1384 | 760 | $3.33 \times 10^4$ | 33 |

Table-VI

## Heat losses with different options

| Proposal No. | Initial Heating time in minutes (minutes) | Oil used in light up litres/day | Heat loss in 8 hr. operation in Kcal | Equivalent oil consumption corresponding to 8 hrs. losses litres/day | Total oil consumption equivalent to heat losses |
|---|---|---|---|---|---|
| 1) | 83 | 138 | $10.71 \times 10^4$ | 22.5 | 160.5 |
| 2) | 60 | 100 | $12.73 \times 10^4$ | 26.8 | 126.8 |
| 3) | 66 | 110 | $4.85 \times 10^4$ | 10.2 | 120.2 |
| 4) | 57 | 95 | $4.75 \times 10^4$ | 10.0 | 105.0 |
| 5) | 52 | 87 | $7.73 \times 10^4$ | 16.2 | 103.2 |
| 6) | 30 | 50 | $4.55 \times 10^4$ | 9.6 | 59.6 |
| 7) | 33 | 55 | $3.33 \times 10^4$ | 7.0 | 62.0 |

# Design and constructional aspects

The life of an installation may be shortened due to faulty design or improper construction in spite of the selection of the right type of refractory. Some of the important aspects of refractory construction are:

**Bond**: Bond in brick work is an arrangement by which the joints between the bricks are staggered in all directions in a pre-determined manner. This ensures stability in construction as well as air tightness. An all header construction is recommended in the hot face of a furnace where heavy refractory wear is anticipated either due to action of molten metal slag or dust laden gas moving at high velocities. Where intermittent repairs to the walls are expected, the working layer is built separately from the main wall.

**Wall thickness:** Structural stability should be taken into consideration while deciding the wall thickness. Walls of 115 mm thickness are not constructed beyond a height of one metre without proper anchorage. From the stability point of view minimum thickness should be around 230 mm which may be suitably increased as the height goes up. Use of metallic sheets with anchoring arrangements, improves the stability of the wall where basic refractories are used. Such anchoring of walls with the furnace structurals should have sliding arrangement to take care of the movement of refractories during heating up and cooling down.

**Mortar joints**: Mortar joints will improve the stability of construction. It also takes care of slight variation in sizes as well as warpages by offering a uniform bedding surface. The mortar joints should be as thin as possible especially where they are in contact with molten metal slag, etc. as in the case of ladles handling molten metals. This can be achieved where the construction is limited to standard bricks. But where special bulky shapes are involved a thicker joint has to be provided as a design allowance. Chemical and physical properties of mortar should be identical to that of the bricks which they are joining. Workability of the mortar is important, in the absence of which, good construction is not possible. The excess mortar applied to the brick surface should come out from the edges when one brick is tapped against the other, to ensure that the joint is full and that there is no open gap.

**Expansion joints**: As explained earlier, refractories expand on heating up. Suitable provision should be made at the time of construction for this expansion to take place without creating undue stresses which may result in failure of the refractories. Usually, expansion joints are built in as the construction proceeds. The necessary provision is made depending on the expansion characteristics of the particular refractory at the operating temperature. Care should be taken to see that the expansion allowance provided is just sufficient as any excess provision will have open joints, after heating up of the furnace which will have detrimental effects. In practice, it has been found that if one could provide for just one half of the theoretical expansion it would suffice. The remaining one half will be absorbed by the mortar joints, or even dry joints between the bricks. In some cases, expansion joints are not built in, either they are provided for at the ends or alternatively the movement of the refractories due to expansion is controlled by allowing the structural to move under controlled loads. Expansion joints must be kept free from foreign matter like clay or brick dust. It is preferable to fill it with some combustible material like saw dust, corrugated paper, cardboard, wooden shavings, etc.

**Structural support**: Refractories are normally held in position with a steel shell or a structural framework comprising buck-stays and tie rods. As failure of structurals by other reason will cause partial failure or even total collapse of refractories. Their alignment, shape etc. should be of equal concern. Periodical checks on the structure should be done as these are likely to lose strength by fatigue. Also important is that the structurals should not get overheated, and therefore, it should be adequately insulated wherever required.

REFERENCE:

1. Refractories—F.H. Norton, John Wiler Publication.
2. Refractories And Their Uses—Kenneth Shaw, Applied Science Publishers Ltd., London.
3. Refractory Materials—G.B. Rothenberg, Noyes Data Corpn., NJ, USA.

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# 7

# Thermal insulation

# Introduction

The need for efficient thermal insulation has become more important with higher operating temperatures and increasing energy costs Prevention of heat leakage by judicious application of thermal insulation is the simplest method of achieving substantial economy in energy consumption. With the advent of technology in insulating materials, many upgraded alternatives are available to engineers for application in industry Though thermal insulation is equally relevant for cryogenic applications, this booklet is limited to medium temperature ranges (50 to 600°C) Insulation for high temperature of 600°C, which are normally encountered in industrial furnaces, is covered in the booklet on 'Refractories' in this series

# Functions of insulation

Thermal insulation serves several functions such as.

i) Saving of energy
ii) Fire protection
iii) Conservation of products
iv) Control of temperature
v) Increased production
vi) Better working conditions

# Principle of insulating materials

Insulators are poor conductors of heat and have low conductivity. Insulating material are porous containing a large number of air cells. The resistance to heat transfer by the insulating material would depend on the number of dormant or near dormant air cells packed in the mass. The air cell would be dormant if its diameter is no larger than the mean free path which, for all practical purposes, could be taken as 0.09 microns. This would be possible if insulating materials could be produced with very low fibre diameters and, space between the fibres be so compressed as to be equal or less than the mean free path. Larger air cells are not dormant, and thus convection currents are set up, due to which air temperature rises, this in turn increases the air pressure and consequently the rate of heat flow This means that for higher temperatures, high density materials should be used.

# Mechanism of heat transfer

Heat is transferred through insulation by any one, or more, of the following modes:

1) Solid conduction through matrix or fibres
2) Gaseous conduction
3) Radiation across gas or air space
4) Convection across gas or air space
5) Overall convection of the hot face to the cold face

Materials vary widely in heat conducting properties. This is expressed by the term thermal conductivity Thermal conductivity is the amount of heat transferred in unit time through an unit area of unit thickness with unit temperature difference across the face. Thermal conductivity of a given material usually increases with rise in temperature. Thermal conductivity values for typical heat insulating material, resistant films and heating surfaces are shown in Table 1

**Table-1**

**Thermal conductivity of different material**

| Material | Density (kg/m³) | Approximate conductivity values (kcal/m hr/°C) |
|---|---|---|
| **A) Insulating material** | | |
| i) Magnesia | 177-225 | 0.051 to 0 066 |
| ii) Mineral wool | 50-250 | 0.035 to 0 087 |
| iii) Calcium silicate | 160-320 | 0.049 to 0.079 |
| iv) Aluminosilicates | 96 | 0.028 to 0.07 |
| v) Glass fibres | 96 | 0.028 to 0 061 |
| **B) Resistant films** | | |
| Water at 0°C | | 0.510 |
| Water at 95°C | | 0.585 |
| Air | | 0.0214 |
| Scale | | 0 99-2 97 |
| **C) Heating surfaces (Values at 100°C)** | | |
| Copper | | 338.0 |
| Aluminium | | 206.0 |
| Cast Iron | | 27 8 |
| Steel (0.5%C) | | 44.7 |
| Brass | | 89.3 |

Conductivity of an insulating material varies with its density, porosity, pore size, (in the case of fibrous materials) fibre diameter and shot content (i e non-fiberized particles of rock or glass wool) It is advisable to compute heat losses, on the basis of test values given by the manufacturers of insulating materials However, K values acceptable for typical insulating materials (magnesia, calcium silicate and mineral wool) are as per British standards 3958 Parts 1-5, permitting inherent variations in product quality, dimensional tolerance and accuracy of fit on application. These are depicted in Fig below

Table-II

## Variations in the values of surface coefficient finish or radiating surface and wind velocity

| Insulation Temperature (°C) | Wind speed (m/sec) | Surface coefficient (kcal/m²/hr/°C) | | |
|---|---|---|---|---|
| | | Ambient air at 30°C | | |
| | | Aluminium | Galvanized M.S. | Cloth, Cement/ Fabric |
| 40 | 0 | 4.70 | 6.41 | 7.84 |
| 40 | 1 | 7.59 | 9.30 | 10.73 |
| 40 | 5 | 13.41 | 15.12 | 16 55 |
| 40 | 10 | 17.98 | 19.69 | 21.12 |
| 50 | 0 | 5.36 | 7.15 | 8.65 |
| 50 | 1 | 8 79 | 10.58 | 12.08 |
| 50 | 5 | 15.71 | 17.51 | 19.00 |
| 50 | 10 | 21.15 | 22.95 | 24.44 |
| 60 | 0 | 5.82 | 7.71 | 9.28 |
| 60 | 1 | 9 62 | 11.51 | 13.08 |
| 60 | 5 | 17 28 | 19.17 | 20.74 |
| 60 | 10 | 23.30 | 25 19 | 26.76 |
| 70 | 0 | 6 21 | 8.19 | 9.84 |
| 70 | 1 | 10 79 | 12.27 | 13.92 |
| 70 | 5 | 18.53 | 20.51 | 22.16 |
| 70 | 10 | 25.00 | 26.97 | 28.62 |

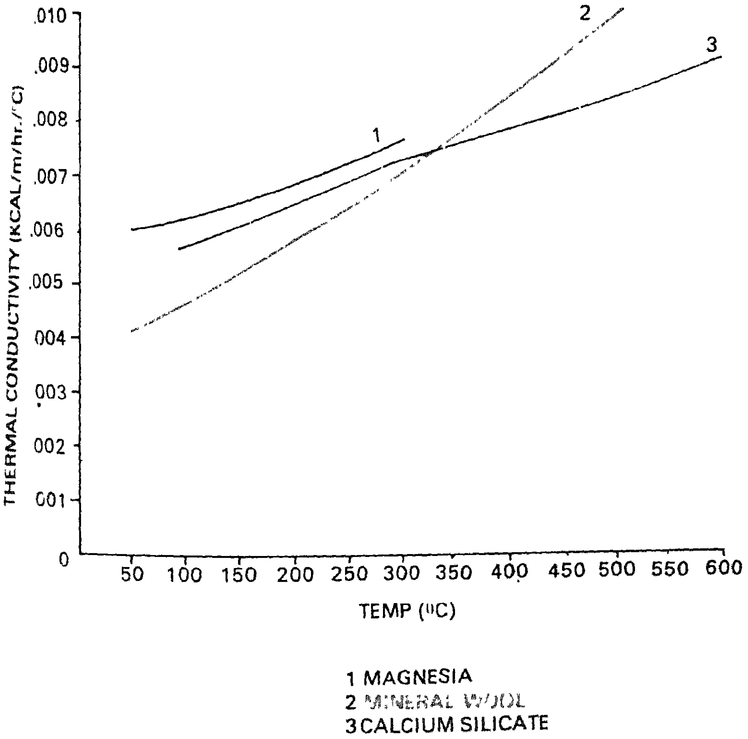


Fig. 1

(Fig. 1)

Heat conducted through an insulating material is transferred to the surrounding air by radiation and convection. For simplicity the combined effect of radiation and convection heat transfers, from the insulation surface is referred to as surface coefficient and is affected by the velocity of air passing over the surface and by emissivity of the surface, which is the rate of heat transfer as compared to that from a black body. Table II shows the variations in the value of surface coefficient with finish of the radiating surface and wind velocity. Variation of surface coefficient effects a large difference in the insulation's surface temperature, but marginal difference to heat loss Table III illustrates the effect of surface coefficient on heat losses and surface temperature for a 150 mm pipe for different temperature values.

**Table-III**

## Effect of surface coefficient on heat loss and surface temperature for a 150 mm pipe in ambient air at 30°C

| Temperature | Insulation | Cloth | | Galvanised mild steel | | Aluminium | |
|---|---|---|---|---|---|---|---|
| (°C) | | q | $t_s$ | q | $t_s$ | q | $t_s$ |
| 100 | 25 mm, K = .041 | 85.9 | 41 | 87.9 | 43 | 78.8 | 46 |
| 100 | 50 mm, K = .041 | 42.0 | 36 | 42.0 | 37 | 40.0 | 39 |
| 300 | 50 mm, K = .052 | 205.5 | 53 | 203.0 | 57 | 196.6 | 63 |
| 300 | 100 mm, K = .052 | 94.1 | 42 | 91.5 | 44 | 91.2 | 48 |
| 500 | 100 mm, K = .067 | 206.5 | 53 | 204.9 | 57 | 201.3 | 64 |
| 500 | 150 mm, K = .067 | 127.9 | 45 | 126.4 | 48 | 124.3 | 53 |

K = thermal conductivity (kcal/hr/m/°C)
$t_s$ = surface temperature (°C)
q = heat loss (kcal/hr/metre run)

$$q = \frac{(\theta_1-\theta_2)K}{L} = (\theta_2-\theta_a)f = \frac{(\theta_1-\theta_a)}{\frac{L}{K}+\frac{1}{f}}$$

Where

$\theta_1$ = the hot face temperature (°C)
$\theta_2$ = the cold face temperature (°C)
$\theta_a$ = the ambient temperature (°C)
L = the thickness of insulation (m)
K = the thermal conductivity of insulation (kcal/hr/m/°C)
f = the surface coefficient (kcal/hr/m²/°C)

The surface temperature may then be calculated from the equation

$$\theta_2 = \frac{q}{f} + \theta_a$$

For cylindrical surfaces, heat losses are given by

$$q = \frac{(\theta_1 - \theta_a)}{r_1\left(\log_e \frac{r_2}{r_1}\right) \times \frac{1}{K} + \frac{r_2}{r_1} \times \frac{1}{f}}$$

q = heat loss (kcal/hr/m²)
$r_1$ = the inner radius of insulation (m)
$r_2$ = the outer radius of insulation (m)

The surface temperature can then be calculated from the equation

$$\theta_2 = \left(\frac{q}{f} \times \frac{r_1}{r_2}\right) + \theta_a$$

Increased air movement has a greater effect on heat loss from bare piping than from insulated piping. Table IV below, shows the effects of wind velocity on heat loss from bare and insulated surfaces.

**Table -IV**

### Effect of wind velocity on heat loss

| Wind velocity (m/sec) | Heat loss (kcal/m/hr) | | | | |
|---|---|---|---|---|---|
| | Bare | 25 mm Insulation | 50 mm Insulation | 75 mm Insulation | 100 mm Insulation |
| 0 | 3415 | 507 | 307 | 232 | 191 |
| 1 | 4197 | 537 | 319 | 238 | 198 |
| 5 | 7086 | 572 | 330 | 247 | 205 |
| 10 | 10490 | 576 | 336 | 248 | 206 |

Details: 150 mm pipe at 300°C
Ambient temperature = 30°C
Insulation K = 0.0515 kcal/m/hr/°C
Finish· Galvanized Mild Steel

## Choice and properties of lagging material

### Cork, Felt and Straw

These are natural and the cheapest lagging material available. Cork is probably the best of all materials due to its intricate natural structure These materials are useful for temporary lagging as they can be conveniently wrapped around pipes with single strands of wire and string. They should not be used for surfaces hotter than 200°C as they are inflammable and get charred and brittle at moderate temperatures.

### 85% Magnesia

This is light calcined magnesium carbonate with 15% amosite asbestos, moulded into standard pipe sections and other shapes. It is excellent, robust and economical in operation, but requires protection from the weather. It should not be used on surfaces whose temperature is over 300°C. This disadvantage can be overcome by interposing a thin layer of special cement between magnesia and the hot surface. Use of Magnesia as insulation has become obsolete these days.

### Asbestos

Asbestos is a natural mineral consisting of a variety of complicated silicate compunds generally containing calcium or iron or both. There are many different types of asbestos used for lagging purposes — e.g. asbestos fibres and textiles produced by textile machinery in the form of opened fibre, yarn, sheet and mattresses which can be used upto temperatures of 250°C.

Asbestos or plastic sections and coatings which consist of short amosite or crocidolite fibres with a blending agent sprayed or moulded, can withstand temperatures upto 600°C.

Asbestos fibres are in general fire proof material of very low thermal conductivity. However, its use is being discontinued in some European countries due to health restrictions.

### Glass wool

This is supplied as a staple fibre, continuous filaments, or in the form of mattresses, or in the form of semi rigid bonded slabs.

Glass wool is relatively expensive, it irritates sensitive skin and can only be used on surfaces with a maximum temperature of 550°C, when loose and upto 250°C when bonded.

### Slag wool and rock wool

These are made by centrifugal spinning process from molten slag or mineral rocks.

They are good heat insulators and are comparatively less costlier. They can be applied to hot surfaces with temperatures upto 850°C and are available in the form of mattresses, blankets, moulded sections and insulating boards.

### Ceramic Fibres

Ceramic fibres are pressed into a blanket for use up to 1700°C.

## Types and forms of thermal insulation

Thermal insulation materials can be divided into four types:

a) Granular
b) Fibrous
c) Cellular
d) Reflective.

Granular, fibrous and cellular types rely on enclosed air or gas and minimum solid conduction paths for their thermal properties. Granular materials such as calcium silicate and diatomaceous earth (kiesel guhr), i e silceous particles composed of skeltons of diatoms, containing air entrained in the matrix. Fibrous materials like mineral wool and refractory fibres contain air between the fibres and cellular materials such as cellular glass and foamed plastics contain small air or gas cells, sealed or partly sealed from each other. Reflective insulation consists of numerous layers or random packing of low emissivity foils such as aluminium. It is possible to have a combination of the above The four types of insulation have varied physical characteristics and as insulation is required for a wide range of services, they are produced in many forms as shown in Table V

**Table-V**

## Forms of thermal insulation

| Form | Description | Examples |
|---|---|---|
| Preformed | Fabricated in such a manner that at least one surface conforms to the shape of the surface being insulated, this shape being permanently maintained. | Rigid slabs & pipe sections of calcium silicate, mineral wool, cork |
| Plastic composition | Insulation in a loose dry form which is prepared by mixing with water. | Magnesia, calcium silicate, diatomaceous earth |
| Loose Fill | Insulation in the form of powdered granules, loose, or pelleted fibres. | Vermiculite, Mineral Wool |
| Flexible | Insulation materials which, lacking rigidity, tend to conform to the shape of the surface against which it is laid. | Low density mineral wool |
| Textile | Insulation in the form of rope, cloth, etc. | Asbestos, ceramic fibre ropes and fabrics. |
| Mattress | Flexible insulation faced or totally enclosed with fabric, wire netting, expanded metals, etc. | Wire netted mineral wool mattress, asbestos and glass wool mattresses |
| Reflective | Insulation comprising numerous layers or random packing of low emissivity foils. | Aluminium foil, stainless steel foil |
| Spray applied | Insulation applied by machine in the form of spray. Insulation may be fibrous or granular material mixed with water or other suitable binder. | Sprayed mineral fibre/ceramic fibre |

Typical thermal insulating materials for use in the temperature range of 50 to 1000°C are listed in Table VI below:

**Table-VI**

| Insulation | Type | Availability in form | Density kg/m$^3$ | Thermal Conductivity (kcal/m/hr/°C) | Approximate limiting temp. (°C) |
|---|---|---|---|---|---|
| 1) Cellular glass | Cellular | Slabs, sections | 120-152 | .047 at 50°C | 430 |
| 2) Asbestos | Fibrous | Mattress, textile, loose fill | 80-250 | .042 at 40°C | 600 |
| 3) Glass fibre | Fibrous | Slab, loose fill, mattress | 12-80 | .032 at 40°C<br>.051 at 150°C | 400 |
| 4) Rock wool and slag wool | Fibrous | Slab, preformed sections, mattresses, loose fill, sprayed | 40-250 | .032 at 40°C<br>.036 to .045 at 110°C<br>.005 at 250°C | 800 |
| 5) Calcium silicate | Granular | Slab, section, plastic, brick | 240 | .051 at 40°C | 850 |
| 6) Magnesia | Granular | Slab, section, plastic loose fill | 200 | .05 at 40°C<br>.065 at 200°C | 300 |
| 7) Silica | Fibrous | Loose fill, brick | 50-150 | .033 at 40°C<br>.07 at 250°C<br>.081 at 250°C | 1000 |
| 8) Aluminosilicate | Fibrous | Loose fill, mattress | 50-250 | .028 to .071 | 1200 |
| 9) Aluminosilicate | Granular | Textile, sprayable Brid | 500-800 | — | 1200 |
| 10) Aluminium | Reflective | Reflective | 10-30 | .026 to.036 at 20°C<br>.074 at 250°C | 500 |
| 11) Stainless Steel | Reflective | Reflective | 300-600 | - | 800 |
| 12) Vermiculate | Granular | Plastic, wax fill | 50-500 | .073 at 40°C<br>.093 at 250°C | 1100 |

# Selection of lagging material

The ultimate choice of a thermal insulating material is an engineering decision involving a number of factors, important among such are

1. The operating temperature of the system
2. Thermal conductivity of the insulation
3. Capability of the insulation in application to hot surfaces readily and cheaply
4. Resistance to heat, weather and adverse atmospheric conditions
5. Ability to withstand vibration, noise, and accidental mechanical damage
6. Resistance to chemicals
7. Resistance to fire
8. No shrinkage or cracking during use
9. Jacketing the insulation.
10. Total cost including maintenance costs

# Method of application of insulation

Since most of the insulation materials are fibrous and light, they have to be applied at the correct density without leaving void, and should be properly supported Therefore, the correct method for application of insulation is equally relevant in order to minimise heat losses

The Indian Standards Institution gives guidelines on the method of application of insulation, (Ref IS 7413-1981, Code of Practice for the Application and Finishing of Thermal Insulation Materials at Temperatures between 40°C and 700°C) abstracts from which are given below.

## a) Methods of application

All insulation materials, however fixed, should be applied so as to be in intimate contact with the surface to which they are applied; and the edges, or ends of sections, shall butt up close to one another over their whole surface except in special applications

While applying multi-layer insulation, all joints shall be staggered, and each layer shall be separately secured to the surface

In consideration of possible pipeline movement with change in fluid temperatures, different pipes should be separately insulated

The insulation shall be supported when applied to the sides of, or underneath large vessels or ducts or to long runs of vertical piping. Supports are welded either to the hot surface or to bands which are then strapped round the surface These supports serve to hold the insulation in place, prevent its slipping, or support it above expansion joints. In addition, they provide necessary anchorage for lacing wire or wire-netting which may be required to hold the insulation in place and/or to provide reinforcement for the insulation or a finishing material

### Surface preparation

Before application of the insulation, the surface is wire-brushed to remove dirt, rust, scale, oil, etc and dried

All surfaces are then brush-coated with a suitable anti-corrosive primer before insulating

### Application of insulation

The following methods are available for application of flexible insulation, rigid insulation etc

#### i) Flexible insulation

Flexible materials, namely, mats or blankets faced on one or both sides with a suitable facing material are applied b means of tie wire or metal bands or wire netting on the outer side, and are suitably laced

#### ii) Rigid insulation

Rigid insulation material, namely blocks or boards, may be applied by means of suitable metal bands, or wire netting on the outer surface.

#### iii) Thermal insulating cement

Thermal insulating cements are supplied in the form of a dry powder, which is mixed with water to form a soft mortar of even consistency suitable for application by han or with a trowel

Thermal insulating cements require heat for drying to ensure initial adhesion to the surface All surfaces insulated with thermal insulating cements may, therefore be kept warm throughout the application of the insulation as per specifications by the manufacturer of the cement

#### iv) Loose-fill insulation

This may be adopted by agreement between the purchas and the applicator Loose-fill insulation is recommended for the following cases

a) Expansion/contraction joints in an application when rigid insulation has been used, or

b) Specific areas of the equipment where conventional methods of application may not be possible and whe packing a loose fill is the only possible method of providing insulation

### Specific applications

Insulation of pipes, ducts, vessels, etc , may be suitably carried out by any one of the methods already mentione However, specific considerations pertaining to insulation pipes, ducts, vessels, etc are detailed below.

**Pipes:** On continuous runs of 6 metres or more of vertical pipe, support rings are provided at not more than 3-metre intervals Such rings encircle the pipe and the radial lugs thereon and with specified length equal to 75 per cent of the total insulation thickness.

**Ducts:** When insulation is applied around the corners of the duct, care should be taken to counteract tendency for the material to thin down at these locations.

**Vessels:** All large vertical vessels with a height of 6 metres or more are provided with support rings, at not more than 3-metre intervals. such rings encompass the vessel, and the radial lugs thereon have a length equal to 75 per cent of the total insulation thickness. Extra insulation is provided over the support rings. This extends for 25 cm on each side of the ring and is extended to 45cm for watershed on the upper side.

## Finishing

Protective coverings or finishes are required over the insulation for one or more of the following reasons:

- Protection against mechanical damage
- Protection against weather or chemical attack
- Retardation of flame spread
- Appearance
- Providing the insulation with an easily cleaned surface
- Identification of pipe or vessel

## Protective finishes

The following are the commonly applied protective finishes:

### Finishing cement

Mixtures of cement-sand or cement asbestos or asbestos-plaster of paris, with a minimum thickness of 10 mm or as specified and reinforced with wire netting of minimum 20 mm mesh and 0.56 mm diameter or equivalent metal sheet.

### Bituminous plastics

Minimum of 3 mm thickness with suitable reinforcement such as fabric or wire netting where necessary.

### Sheet metal

Aluminium, galvanized iron or mild steel sheet of suitable thickness with provision of anti-corrosive paint on the inner surface. Galvanized iron or mild steel sheets. Sheets metal, whether applied to pipes or to vessels, may preferably be secured by metal bands.

All joints between adjacent sheets should be either grooved or overlapped, 50 mm minimum against the weather, to prevent the ingress of rain water.

### Asbestos cloth

Roofing felt, jute canvas, scrim cloth are also used.

## Fittings

The word 'fittings' includes flanges, valves expansion/contraction joints and other pipe fittings.

Before insulation on fittings is undertaken, insulation of the pipe, with its protective finish, must be completed. The insulation is stopped short of the fitting on both sides of the fittings so as to allow withdrawal of belts, without disturbing the insulation. The fitting is then insulated.

## Tracer lines

While erecting tracer pipelines, it is necessary to maintain the closest possible contact between the main pipe and the tracer.

Care may be taken to prevent the insulation from filling any space between the main pipe and the tracer

Whatever insulation is applied, the pipe and tracer is encased in aluminium foil (0.1 mm thick) drawn up tight and laced with galvanized iron wire. The wrapped pipe and tracer may then be insulated with flexible insulation of thermal insulating cement in the same way as an ordinary pipe.

## Expansion joints in insulation

Depending on the type of insulation used, the operating temperature and the nature of the plant, it may be necessary to provide expansion joints or vessels or pipes to prevent the insulation from rupturing or buckling when the hot surface expands or contracts.

In all cases where support rings are provided on vessels or vertical pipes for rigid insulation materials, the insulation shall be stopped short about 5 mm from each ring and the space between the insulation and the ring filled with a flexible insulation material.

On horizontal pipes and vessels, insulated with rigid insulation materials or thermal insulation cements, expansion joints filled with flexible insulation material should be provided at suitable intervals.

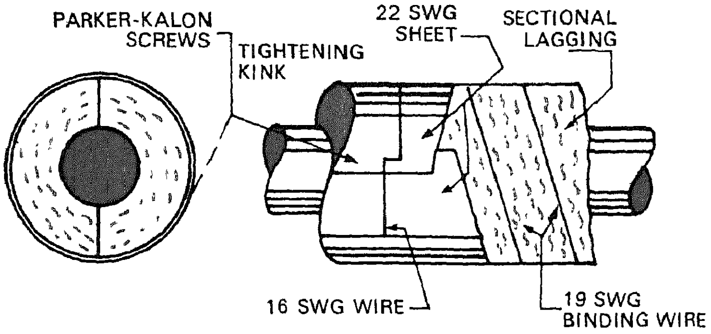
Flexible thermal insulation, for this purpose, mineral wool rigid sections, used at temperatures not exceeding 230°C, do not normally need expansion joints

Where sheet metal is used as the finish, the joints in the sheets over the expansion joints should not be secured with screws.

All other finishing materials may be carried over expansion joints in the insulation without a joint.

# Use of moulded sections

Lagging materials can be obtained in bulk, in the form of moulded sections; semi-cylindrical for pipes, slabs for vessels, etc. The main advantage of the moulded sections is the ease of application and replacement when undertaking repairs for damaged lagging. It is easier to replace a moulded section Most of the damaged lagging can be cut up into wedge sections for covering bends and awkward shapes. While a pipe is being taken down, most of the plasticid lagging is generally lost whereas sections may be recovered intact, with a little care.



SECTIONAL MOULDED LAGGING
Figure 2

Fig. 2 shows the method of fastening the sections to the pipe by a spiral binding of soft wire. For a really neat job, the sheeting should be secured by means of a sheet metal screw. A quick rougher method can be utilised with soft wire binding. The wire should be twisted up fairly tight and when all the wires are in position on one section, the wire may be given a quarter kink with a pair of pliers to do the final tightening without the risk of snapping the wire at twist.

# Lagging flanges

Some engineers generally commit the error of leaving the flanges and valves unlagged while insulating the piping systems In fact, some insulating contractors recommend that flanges should not be lagged if operating temperatures are less than 200°C Such recommendations show a complete lack of knowledge on the economy of insulation. Often, flanges are left bare, due to the fear that leaks may go undetected and that leakages may corrode [illegible] flange bolts.

There are several reasons to dispel this practice. First of [illegible] if the moulded box lagging is used for flanges, a 75 mm length of a 6 mm pipe may be inserted into the bottom of the box to give an early warning of any leak. Secondly, a really bad leak will soon make itself known Third, lagging the flanges is one of the best ways of stopping leaks

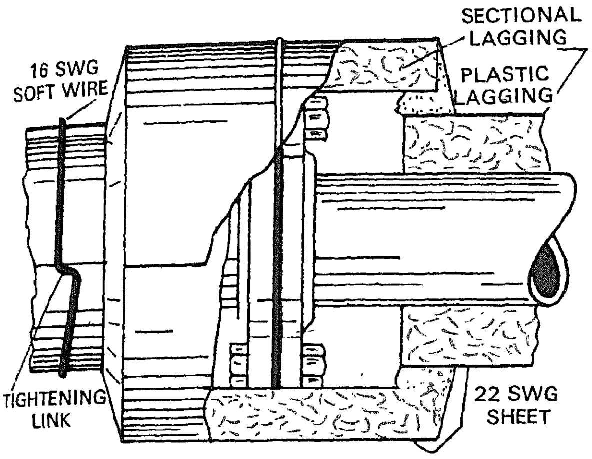
Bare flanges on hot lagged pipes introduce temperature stresses at the flanges which may be the cause of leaks Fig 3 gives a sectional view of moulded lagging on pipe flange protected by sheet metal The heat loss from uninsulated flanges and valves is equal to approximately that from a 0 5 metre and a 1 metre bare piping respectively The heat loss from an uninsulated flange may equal that from several metres of insulated piping, and a piping system with bare loss compared to that of a fully insulated system The effect of retaining uninsulated piping, flanges and valves can be seen from Table VII below

**Table VII**

**Equivalent fuel loss from uninsulated surface**

| | Litres of furnace oil/ annum/metre length | | | | |
|---|---|---|---|---|---|
| **Temperature (°C)** | **Pipe dia (25mm)** | **Pipe dia (50mm)** | **Pipe dia (75mm)** | **Pipe dia (100mm)** | **Pipe dia (150mm)** |
| 50 | 15 | 28 | 40 | 50 | 68 |
| 100 | 74 | 133 | 190 | 250 | 360 |
| 150 | 160 | 288 | 410 | 472 | 660 |
| 200 | 248 | 426 | 620 | 786 | 1136 |
| 250 | 340 | 628 | 916 | 1182 | 1713 |
| 300 | 482 | 895 | 1290 | 1628 | 2428 |

**Assumptions**
a) Ambient Temperature 30°C for still air
b) Hr of operation 8100
c) Pipe external surface Mild Steel



SECTIONAL MOULDED LAGGING ON PIPE FLANGE
PROTECTED BY SHEET STEEL

Fig 3)

Table VIII below shows the equivalent wastage of bare surfaces

**Table-VIII**

| Temperature (°C) | Surface coverd with aluminium sheet (Litres/annum) | Surface covered with galvanized mild steel (Litres/annum) |
|---|---|---|
| 50 | 80 | 113 |
| 100 | 366 | 520 |
| 150 | 708 | 1050 |
| 200 | 1118 | 1757 |
| 250 | 1588 | 2660 |
| 300 | 2116 | . 4194 |

**Calculations based on**

5000 hours/year
Average ambient: 30°C
Still air condition
Boiler efficiency: 81 8%
Gross Calorific Value 10,300 kcal/kg
Sp gravity of oil 0.95

# Insulation of boilers

Boilers for power plants and industrial applications have membrane walls or skin casings on which thermal insulation is applied directly to the walls, without the need for any refractory protective materials Maximum temperatures to which the boiler wall insulation is subjected are saturated steam conditions, which would not normally exceed 350°C. Insulation of large boiler walls is usually achieved by the application of mineral fibre slabs, applied in two layers, secured to studs and finished with either galvanized mild steel or aluminium. The insulation chosen should be sufficiently resilient to accommodate relative thermal expansion between boiler wall and outer metal finish.

# Insulation of gas flues

Gas flues are insulated to maintain the required gas temperature in the chimney and to prevent corrosion by maintaining the temperature of flue walls above the dew point of gases. The vertical sides and bottom of the flue may be insulated with low density insulation, supported on studs and reinforcing mesh, but the top of the flue which is liable to foot traffic should be insulated with material of sufficient resistance to compression, in order to withstand imposed loads. The tops are normally insulated with calcium silicate or high density mineral wool. Expansion joints in gas flues should be insulated to prevent acid deposition.

# Open top tanks

Open top tanks containing hot liquids lose energy through evaporation Heat losses can be appreciably reduced by floating a layer of polypropyline (plastic) spheres on the surface of the liquid Manufacturers claim a reduction of 70% heat losses by floating a layer of 45 mm diameter balls on the surface of liquids at 90°C.

# Insulating stainless steel surfaces

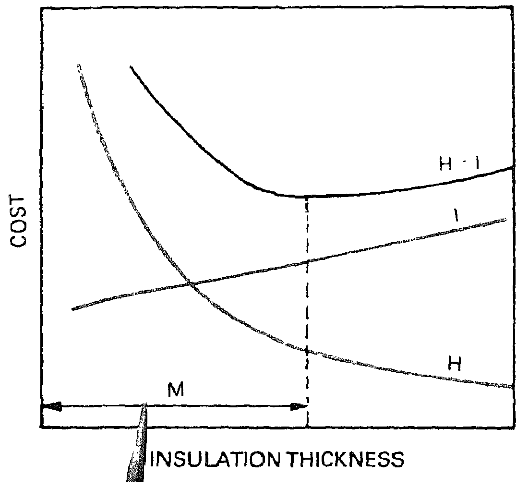
Insulated austenitic stainless steel surfaces operating at temperatures above 70°C are liable to external stress corrosion, and cracking in the presence of chlorides. As most thermal insulating materials contain chlorides when manufactured, and may also pick up chlorides from the atmosphere, it is necessary to take precautions when insulation is applied to stainless steel piping and equipment. It is recommended that a barrier be placed between the insulation and the stainless steel to prevent chlorides that may be leached out from being deposited on the stainless steel. The usual practice is to apply and fit aluminium foil no thinner than 0 06 mm before the insulation is applied.

Painting treatments may also be applied to stainless steels before insulation is applied. Furthermore, stainless steel surfaces should be adequately water-proofed to prevent ingress of water.

# Optimum economic thickness

Insulation of any thermal system means capital expenditure Hence, the most important factor in any insulation system is to analyse the thermal insulation with respect to cost

The effectiveness of insulation follows the law of diminishing returns Hence, there is a definite economic limit to the amount of insulation which is justified, i e there is a thickness below which the insulation is insufficient and loss of heat is more An increased thickness is wasteful in terms of cost, and cannot be recovered through small heat savings This limiting value, termed as economic thickness of insulation (ETI) is that thickness of insulation at which the costs of heat loss, plus the installed cost of insulation is at a minimum, over a given period of time Fig 4 below demonstrates this principle



DETERMINAT[illegible]N OF THE ECONOMIC THICKNESS OF INSULATION [illegible]ATERIAL.

I  COST [illegible] INSULATION  H  COST OF HEAT LOSS
I + H  TOT[illegible] COST  M  ECONOMIC THICKNESS

(Fig. 4)

The determination of economic thickness requires the attention to the following factors:

- i) Value of fuel (fuel cost plus cost of labour, maintenance, etc )
- ii) Annual hours of operation
- iii) Heat content of fuel
- iv) Efficiency of combustion of fuel
- v) Average exposure ambient still air temperature
- vi) Operating temperature of surface
- vii) Pipe diameter/thickness of surface
- viii) Estimated cost of insulation installed
- ix) Amortization period
- x) Heat loss per linear metre (or square metre, if a flat surface is used).

After compiling the above data, the economic thickness is determined by first computing the heat loss per year on 100 metres of the surface Then the installed insulation cost per year is calculated The latter figure is equal to the cost of 100 linear metres of insulation divided by the amortization period Finally, the cost of heat is added to the insulation cost After this summation is plotted for various values of insulation thickness, the lowest point on the curve indicates economic thickness, thus economic thickness pays for itself besides earning a return over its original cost From this definition, any changes occurring in the prices of fuel or in the insulation cost will tend to shift the economic thickness to another value Hence the insulation levels which were uneconomical in the 70's may be quite lucrative now due to the drastic increase in fuel prices in the recent years Based on the prevailing cost structure one has to review the entire insulation system and assess if any additional insulation is necessary to achieve optimum economy Mathematical analysis for determining optimum economic thickness is as under:

**Cost of heat loss per year**

$$= \frac{q \times N}{n \times H} \times P \text{ in Rs/year}$$

where N = No of hours of operation of plant per year
P = Price of fuel in Rs/kg
n = Efficiency of steam generation plant
H = Gross calorific value of fuel in kcal/kg
q = Heat in kcal/hr

**Annual cost of insulation**

$$= c/a$$

where c = cost of insulation including outer protection covering.

$$\text{Amortization period} = a = \frac{1}{\frac{r}{100} + \frac{1}{z}} \text{ Year}$$

Where r is the percentage return on capital and z is plant life in years.

The cost of heat losses per year is computed for a range of insulation thickness at 10 mm intervals and tabulated.

These costs are added to each thickness and from that the minimum cost becomes apparent.

The following case illustrates the computation of economic thickness.

**Example**

A process industry has a package boiler using furnace oil as fuel. Efficiency of the package boiler is 80%. The plant operates for 6000 hours each year. It is now required to calculate the economic thickness of insulation for

a) a flat surface whose hot face temperature is 100°C
b) a cylindrical surface (steam pipe) where the hot surface temperature is 150°C

Insulation material being used in both the cases is mineral wool with a density of 120 kg/m³. The outer surface of the insulation is covered with thin aluminium sheet of 0.56 mm thickness.

| | |
|---|---|
| Cost of fuel (furnace oil) | = Rs 2.80/kg |
| Calorific value of fuel | = 10300 kcal/kg |
| Boiler efficiency | = 80% |
| Plant operational hours/year | = 6000 |
| Rate on Capital required | = 20% = 0.20 |
| Assume Plant Life | = 5 years |
| Average ambient temperature | = 30°C |
| Cost of useful heat | $= \frac{2.80}{0.8 \times 10300}$<br>= Rs 0.00033/kcal. |
| Years of repayment (amortization period) | $= \frac{1}{0.20 + \frac{1}{5}} = 2.5$ years. |

## a) Tabulation of heat losses and cost of insulation for flat surface at 100°C

| Insulation thickness (mm) | Heat loss/year kcal/m² | Annual cost (Rs/m²) of Heat loss (kcal) (a) | Annual cost (Rs/m²) of Insulation* (b) | Total cost (Rs/m²) (a) + (b) |
|---|---|---|---|---|
| 25 | 69.0 | 138 | 48 | 186.0 |
| 50 | 45.6 | 91.2 | 57 | 148.2 |
| 75 | 31.84 | 63.68 | 65 | 128.68 |
| 90 | 27.53 | 55.06 | 75 | 130.06 |
| 100 | 24.77 | 49.54 | 81 | 130.54 |
| 115 | 21.57 | 43.08 | 87.5 | 130.58 |

Obviously, optimum thickness = 75 mm.

*Annual cost of insulation $= \frac{\text{Total cost of insulation}}{\text{Amortization period}}$

## b) Tabulation of heat losses and insulation cost for cylindrical surface at 150°C

| Insulation thickness (mm) | Heat loss/year | | Annual Cost (Rs/100m) of | | |
|---|---|---|---|---|---|
| | $\frac{kcal}{m^2}$ | $\frac{kcal}{100\ m}$ | Heat loss (kcal) (a) | Insulation* (b) | Total cost (Rs/100m) (a) + (b) |
| 25 | 152.68 | 3817 | 7642 | 1660 | 9302 |
| 40 | 128.16 | 3204 | 6408 | 2140 | 8548 |
| 50 | 116.38 | 2909.5 | 5819 | 2480 | 8299 |
| 65 | 103.76 | 2594 | 5188 | 3027 | 8215 |
| 75 | 98.08 | 2452 | 4904 | 3320 | 8224 |
| 90 | 90.60 | 2265 | 4530 | 4220 | 8750 |
| 100 | 88 80 | 2220 | 4440 | 4540 | 8980 |

Therefore, optimum thickness = 65 mm.

However for quicker evaluation of insulation levels required, the following approach may be adopted.

i) Table IX below depicts the insulation level required for insulating hot surfaces (pipes and flat) as a rough guideline for small and medium industries

$$*\text{Annual cost of insulation} = \frac{\text{Total cost of insulation}}{\text{Amortization period}}$$

**Table-IX**

### Recommended insulation thickness for cylindrical and flat surfaces

| Temperature (°C) | Pipe | | | | Flat (mm) |
|---|---|---|---|---|---|
| | 25 mm dia | 50 mm dia | 75 mm dia | 100 mm dia | |
| Upto100 | 25 | 40 | 50 | 65 | 75 |
| 100-150 | 40 | 50 | 65 | 75 | 100 |
| 150-200 | 50 | 65 | 75 | 100 | 125 |
| 200-250 | 50 | 75 | 100 | 125 | 150 |
| 250-300 | 65 | 90 | 115 | 150 | 175 |

a) The above insulation thickness is for mineral wool backed by a bright metallic surface

b) It is assumed that furnace oil is the source of thermal energy. Prevailing price of furnace oil is taken as Rs2,800/tonne

c) Average utilisation of equipment is assumed to be 6000 hrs/annum

ii) Though surface temperature of the insulation cannot indicate absolutely its effectiveness, yet the following norms may be adopted to evaluate the use of improving insulation levels.

For a wall insulated surface, ΔT (temperature difference) between the surface temperature of insulation and ambient air should be less than the values indicated in the following table:

### Table-X

## Desirable temperature differential between surface and ambient temperature

| Finish | Pipe dia less than 10 mm | | Pipe dia greater than 100 mm flats | |
|---|---|---|---|---|
| | operating temp. less than 250°C | Operating temp. greater 250°C | Operating temp. less than 250°C | Operating temp. greater than 250°C |
| Bright Aluminium Galvanised Sheet | < 15 | < 15 | < 15 | < 20 |
| Dull Finish (cloth) cement, rough sheet | < 10 | < 10 | < 15 | < 15 |

# REFERENCE:

1 Efficient Use of Steam — Oliver Lyle
2 The Efficient Use of Fuel — HMSO, London
3 Refractories And Their Uses — Kenneth Shaw, Applied Science Publishers Ltd., London

# Courtesy—

1 M/s Econtherm Systems Pvt. Ltd., New Delhi
2 M/s Lloyd Insulation (Pvt.) Ltd., New Delhi.

This booklet is one of a series on fuel oil conservation, others in the series are·

1) Storage, handling and preparation of fuel oil
2) Combustion of fuel oils & burners -- operation and maintenance
3) Efficient generation of steam
4) Efficient utilisation of steam
5) Fuel economy in furnaces and waste heat recovery
6) Refractory.

## Other books available with us are:

1) Energy Audit
2) Efficient operation of boilers and furnaces — an operators guide (available in 10 languages)

## PCRA films available for industrial sector:

1) Tuning of Boilers and Furnaces
2) Handling of Fuel Oils
3) Efficient Utilisation of Steam in Industries (under production).

# Notes

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6) Thermal insulation.

**PCRA films available for industrial sector:**

1) "Tuning of Boilers and Furnaces".
2) "Handling of Fuel Oils".
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**SAVE OIL.**
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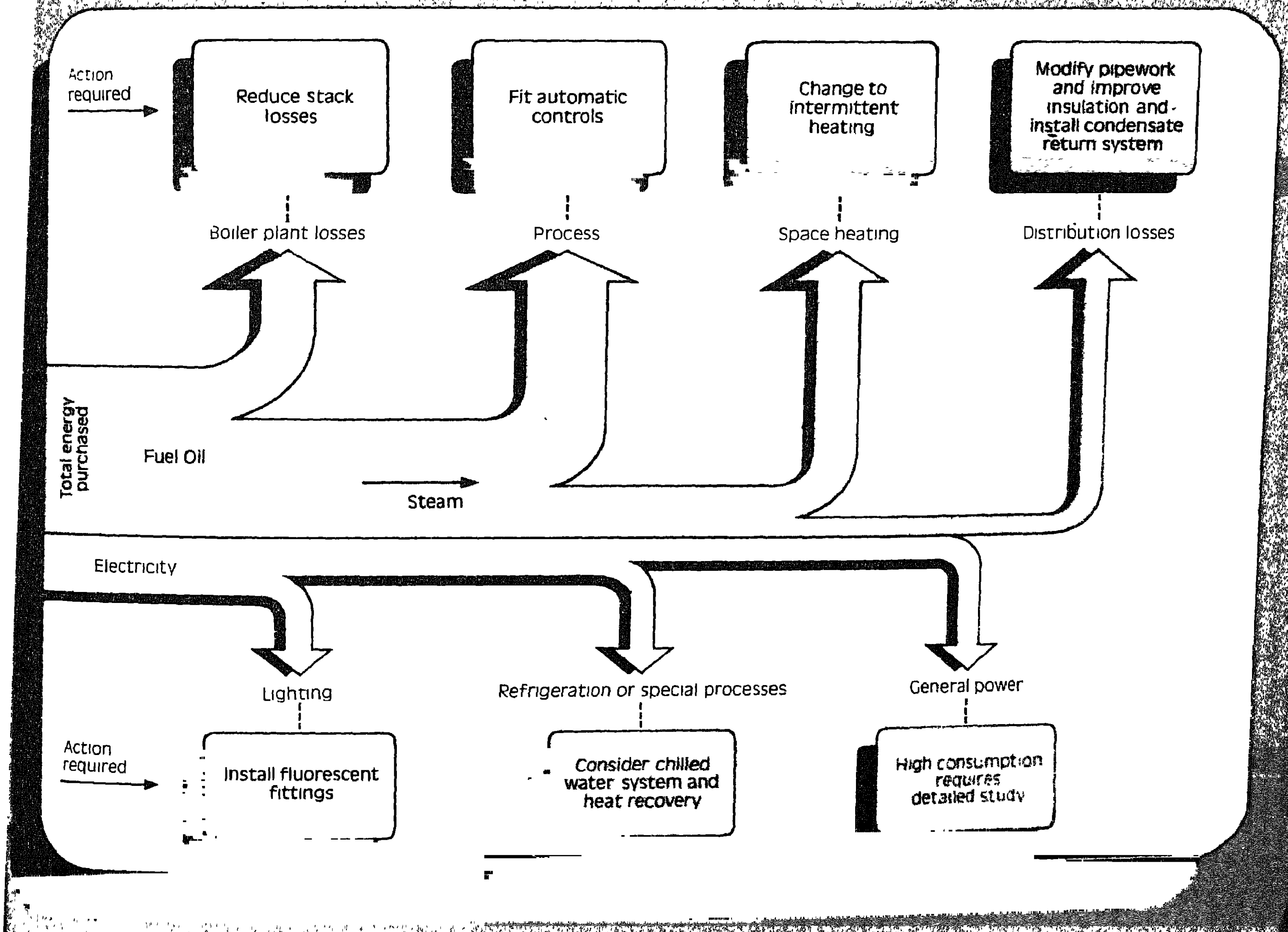
# AN APPROACH TO ENERGY AUDIT


Action required
Reduce stack losses
Fit automatic controls
Change to intermittent heating
Modify pipework and improve insulation and install condensate return system
Boiler plant losses
Process
Space heating
Distribution losses
Total energy purchased
Fuel Oil
Steam
Electricity
Lighting
Refrigeration or special processes
General power
Action required
Install fluorescent fittings
Consider chilled water system and heat recovery
High consumption requires detailed study

# INTRODUCTION

This booklet highlights the importance of 'Energy Audit'. It describes what is Energy Audit, and sets out "why" and "how" in an organisation Energy Audit should be carried out.

The approach adopted in this booklet is of a general nature. It will, however, serve as a guideline to any organisation. This is because no two organisations use energy in the same manner.

As Energy Audit directs and controls the energy management programmes, this booklet is aimed at Engineers as well as Management Executives.

# ENERGY AUDIT

A lot of publicity has already been given to encourage energy conservation but not much is known about the specific ways and means to achieve the same. Energy Audit deals with this aspect at length.

Energy Audit is the key to a systematic approach for decision-making in the area of energy management. It attempts to balance the total energy inputs with its use, and serves to identify all the energy streams in a facility. It quantifies energy usage according to its discrete functions.

Industrial Energy Audit is an effective tool in defining and pursuing comprehensive energy management programmes. In this field also, the basic functions of management like planning, decision-making, organising and controlling, apply equally as in any other management subject. These functions can be effectively performed, based on reliable information which can be made available to the top management by applying Energy Audit techniques.

# THE NEED

With the advent of energy crisis and exponential hikes in the cost of different forms of energy, Energy Audit is manifesting its due importance in various sectors. Energy Audit will help to understand more about the ways energy and fuel are used in any industry, and help in identifying the areas where waste can occur and where scope for improvement exists.

The Energy Audit would give a positive orientation to the energy cost reduction, preventive maintenance and quality control programmes which are vital for production and utility activities. Such an audit programme will help to keep alive variations which occur in the energy costs, availability and reliability of supply of energy, decide on appropriate energy mix, identify energy conservation technologies, retrofits for energy conservation equipment and the like.

In general, Energy Audit is the translation of conservation ideas into realities, by blending technically feasible solutions with economic and other organisational considerations within a specified time frame. This technique will be more beneficial than piece-meal injection of short-term measures, without adopting a scientifically evolved strategy including gearing up of organisational structure and other infrastructural requirements.

# TYPE

Energy Audit attempts to balance total input of energy with its use. The type of Energy Audit to be performed depends on:

— the function and type of industry,
— the depth to which final audit is needed, and
— the potential and magnitude of cost reduction desired.

The primary objective of Energy Audit is to determine ways to reduce energy consumption per unit of product output or to lower operating costs. The extent and type of Energy Audit should result in gains commensurate with the efforts.

There can be two types of Energy Audit—

i) Preliminary Audit
ii) Detailed Audit

Preliminary Audit is performed in a limited span of time. It focuses on major energy supplies and demands, accounting for at least 70 per cent of total energy requirements. The Detailed Audit goes beyond quantitative estimates to costs and savings. It includes engineering recommendations and well defined projects with priorities. It accounts for approximately 95 per cent of energy utilised in the plant. A long range energy plan can be drawn up on the basis of data generated and analysed.

The Preliminary Audit can be an effective follow up for measuring the progress of the Plant Energy Management Programme (if any) that has been drawn up earlier. It may also form the basis for deciding the modalities of Detailed Audit.

The two types of audit are compared & shown in Table - 1

## TABLE-1

| | Preliminary Audit | Detailed Audit |
|---|---|---|
| Objective | Set priorities for optimising energy consumption. | a) Quantify energy consumption/utilisation.<br>b) Evolve detailed engineering for options to reduce energy costs/consumption. |
| Scope | Highlight energy costs and wastages in major equipment/processes. | Formulate a detailed plan on the basis of quantitative and control evaluation. |
| Duration | 2 to 10 days. | 1 week to 10 weeks. |
| Audit frequency | Difficult to decide. | May be 2 to 3 years in normal cases* |
| Preparation | a) No pre-audit visit required.<br>b) Detailed questionnaire to be compiled before the audit. | One/two pre-audit visits required.<br>In addition to points for preliminary audit, the following points have to be taken care of:<br>i) Advance notice to departmental heads.<br>ii) Arranging for office and secretarial support.<br>iii) Advance tentative schedule.<br>iv) Audit kit to be meticulously planned/ arranged. |
| Due date | Within two weeks of completion of field work. | Within 3 months of completion of field work. |

* However, for energy intensive industries it may be on an annual basis.

## METHODOLOGY

here is no set methodology which can be readily ailor-adapted for conducting Energy Audit in all lants. What works in one plant may fail in another. It epends on the management philosophy, history and ulture of organisation, type of plant and machinery, inancial conditions of the company and technological nd process intricacies. In essence, Energy Audit directs and controls the energy management programme. A general questionnaire is, however, given in Appendix-I which will help in identifying areas while carrying out an Energy Audit study. An energy management programme which can be steered through a well conceived Energy Audit system is highlighted hereafter.

## PRE-REQUISITES

Before starting any energy management programme, the top management should assign the responsibilities of energy accounting, auditing and analysis to an internal and/or an external group. The executives from various departments like production, utilities, maintenance and finance should be brought together in order to review the findings at periodic intervals..

Necessary financial, organisational and infrastructural support for implementing and reviewing energy conservation measures should be provided to this group.

The involvement of the representatives from different departments/labour unions is necessary to make the energy conservation measures effective.

## SCOPE

The needs and objectives of the Energy Audit are to be identified. The functional areas to be studied are selected, based on overall energy consumption figures of the organisation.

The scope of an Energy Audit varies according to the facilities being audited. At one extreme is a light manufacturing operation where lighting, ventilation and air-conditioning are the major energy uses. While at the other end, there are integrated process units like refineries and petrochemical plants, where cascading of energy and complex energy balances are involved. The different scopes of Energy Audit are listed in Table 2.

## TABLE-2

### SCOPE OF ENERGY AUDIT

- Analyse present consumption and past trends in detail.
- Review lighting requirements.
- Consider submetering.
- Compare standard consumption to actual.
- Produce an energy balance diagram for the firm.
- Review existing energy recording systems.
- Compare consumption with other locations, other firms, previous period and budget.
- Check records against invoices.
- Compare meter reading against records.
- Review records of maintenance engineer.
- Check capacities and efficiencies of equipments.
- Check working of controls.
- Examine need for automatic controls.
- Determine adequacy of maintenance.
- Review fuel storage and handling.
- Examine need for improved instrumentation.
- Consider training energy management staff.
- Review new projects with respect to energy use.
- Introduce life cycle costing.
- Consider changing the management information system to include energy parameters.
- Develop energy use indices to compare performance/productivity.
- Introduce energy use monitoring procedures.
- Check frequency of energy reporting systems.
- Examine and monitor new energy saving techniques.
- Examine need for energy saving incentives.
- Consider publicity campaigns and incentives.

## DATA COLLECTION

Basic data concerning the overall energy consumption, its cost and production figures for a period of the preceding five years have to be collected. These figures, when compared, give a trend of energy consumption and its cost per unit production over the years. The data can be compiled in different formats given in Tables 3,4,5. Energy consumption in different forms should be expressed in a common unit (Kcal/Kwh/GJ) to facilitate easy comparison. Appendix-II may be referred to for various energy conversion factors. As energy consumption is also related to production figures. it should be expressed in a common term viz., specific energy consumption — Kcal/unit of production.

## TABLE-3 ENERGY CONSUMPTION FIGURES

| | TYPE OF ENERGY | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| YEAR | FUEL | | | | | | | | | | | | ELECTRICITY | | | | | | | Total Kcal | Total Cost |
| | FURNACE OIL | | | | | | COAL | | | | | | | | | | | | | | |
| | MT | Rs./ MT | Rs. | Rs./ Kcal | % of Total Kcal | % of Total Cost | MT | Rs./ MT | Rs. | Rs./ Kcal | % of Total Kcal | % of Total Cost | KWH | Rs./ Kwh | Rs | Equi. Kcal | Rs./ Kcal | % of Total Kcal | % of Total Cost | | |
| | (1) | (2) | (3) | (4) | (5) | (6) | (1) | (2) | (3) | (4) | (5) | (6) | (1) | (2) | (3) | (4) | (5) | (6) | (7) | | |
| 1978 | | | | | | | | | | | | | | | | | | | | | |
| 1979 | | | | | | | | | | | | | | | | | | | | | |
| 1980 | | | | | | | | | | | | | | | | | | | | | |
| 1981 | | | | | | | | | | | | | | | | | | | | | |
| 1982 | | | | | | | | | | | | | | | | | | | | | |
| 1983 | | | | | | | | | | | | | | | | | | | | | |

## TABLE-4 PRODUCTION FIGURES

| Year | Production, Tonnes | Total Energy consumed, Kcal | Specific Energy consumption of finished product, Kcal/Tonne |
|---|---|---|---|
| 1978 | | | |
| 1979 | | | |
| 1980 | | | |
| 1981 | | | |
| 1982 | | | |
| 1983 | | | |

## TABLE-5

| S.No. | Item | Type of Energy used | | Total energy consumption MT/KL/Kcal |
|---|---|---|---|---|
| | | FUEL MT/KL | ELECTRICITY KWH | |
| 1. | Machines | | | |
| 2. | Compressor | | | |
| 3. | Lighting | | | |
| 4. | Heating | | | |

The collection of data as indicated in the previous tables, needs metering facilities for energy used in different sections/departments. A fair approximation of energy consumption in different processes/equipment can be made with the help of different standard data given in appendices-III to VI.

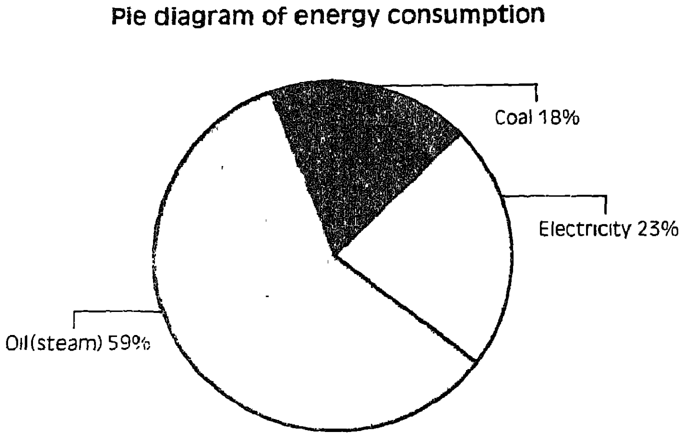


Fig.1

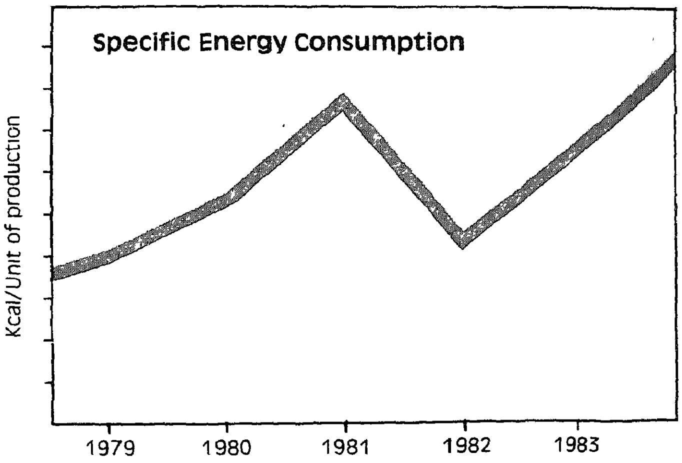


Fig.2

## Data Analysis

When sufficient data has been built up, the existing records of consumption should be reviewed. The energy consumption and production figures available can be refined to an appropriate form.

A pictorial representation e.g. pie diagram, can be made to indicate the share of different forms of energy in the total energy consumption of the unit (Fig.1).

A graphical representation of energy input per unit of product (specific energy consumption) over the years, as shown in Fig.2, will give an immediate insight into the trend of energy consumption. An increasing trend would call for a serious involvement in holding the line.

A sankey diagram, as illustrated in Fig.3, can be drawn for accounting energy use and losses in the plant. This can be accompanied by actions required for curtailing the consumption.

Sankey diagram of energy input and end uses: all units. are in kw. i e 3412 Btu/h or 3.600 MJ/h

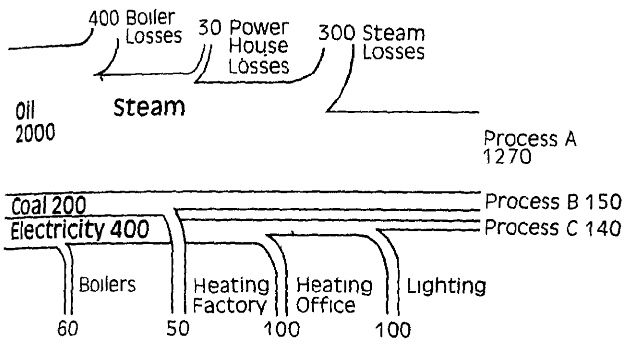


Fig.3

By making a graph of specific energy consumption against product output from a large number of readings or as a result of trials, (Fig.4), it may be possible to pick out the best set of figures which can be used as a target for future output or to optimize the process for energy use. The comparison of specific energy consumption with similar units and/or a theoretical exercise for the same will also help in fixing targets.

**Specific Energy Consumption**

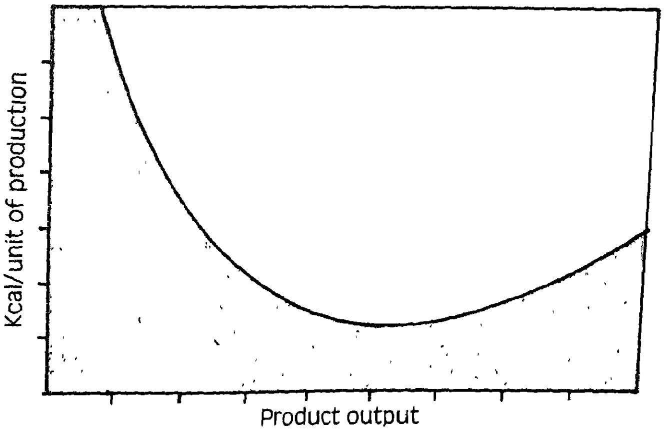
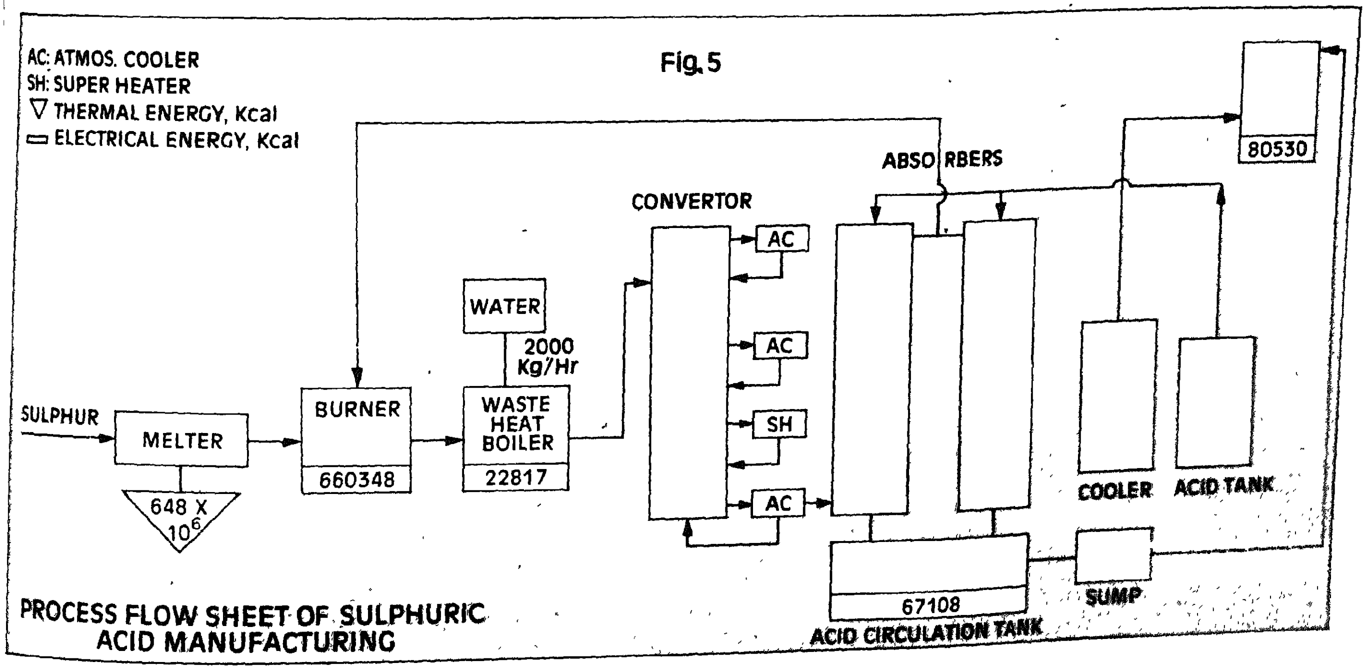


Fig.4

A process flow diagram with energy consumption in each step/operation could be made which will indicate the order of energy consumption in different operations.

This is illustrated in Fig.5. Refining the data in various forms would thus help in locating the areas of high energy consumption, high costs and savings potential.



PROCESS FLOW SHEET OF SULPHURIC ACID MANUFACTURING

## ENERGY CONSERVATION PROPOSALS

Energy Audit results in energy conservation proposals or projects. Initially, proposals with minimum investments are identified such as

- Improvements in the standard maintenance of thermal insulation, instrumentation, combustion equipment, etc.
- Carrying out of plant efficiency trials
- Excess air control
- Stopping leakages
- Re-allocation of electric motors.

The criteria used for ranking the proposals are the savings achievable from a project compared to the investments needed for effecting these savings. The savings to investment ratio (SIR) is calculated and the project with the highest SIR is selected first then the next highest and so on Proposed projects, however, should provide an adequate financial return on the capital required to complete them. A discounted Cash Flow and/or Life Cycle Cost Analysis of the project should be carried out to get a complete economic analysis of the proposal. The following guidelines are recommended for approval of smaller size, working budget type, energy conservation projects.

| Anticipated Real Project Life | Payback |
|---|---|
| 5 years | 2 years |
| 10 years | 3 years |
| 15 years | 4 years |

An effective campaign on educating the employees in the unit by way of posters, house magazines, suggestion box, involvement of unions, training programmes and incentive schemes should be given due attention to help imbibe the energy conservation attitude.

## CONTROL

A reporting system of energy consumption should be devised and incorporated in the Management Information Systems. This will help in evaluating and reviewing the different energy conservation programmes implemented.

This necessarily calls for proper metering system at key points. The reliability of the data is most important. It, otherwise, would jeopardise the whole exercise. The data thus generated will give a clear picture of the status of different energy conservation proposals/projects against the targeted value. It leaves enough room to re-organise the programmes accordingly, if the results are found far short of the target.

## PERIODICITY OF THE AUDIT

It is too much to expect a common answer to the question of periodicity of Energy Audit. It depends on the type of audit undertaken previously, pace of implementation of energy conservation programme in the recent past, overall potential for energy conservation and several other factors. It can be better decided by professionals involved in the latest Energy Audit exercise undertaken in the plant or on the basis of a preliminary audit, specially being undertaken for the above purpose However, for a beginning the periodicity suggested in Table-I would be adequate.

## CONCLUSION

Energy Audit is an effective tool in defining and pursuing a comprehensive energy management programme. A careful audit of any type will give the unit a plan with which it can effectively manage the plant energy system at minimum energy costs. This approach would be useful for industries in combating escalating energy costs and also reap several other benefits like improved production, better quality, higher profits, lower emission, etc. The approach would broadly be the same in any type of industry and service. The basic formats may have to be suitably modified for different types of industries.

# GENERAL QUESTIONNAIRE

## I. Internal Control Questionnaire

Name of company: ........................ ...........

Location. .......................................

Official(s) interviewed: ........................

### A. Control of Energy

1. Who is responsible for energy management?
   Name:
   Position in organisation:
   Full time or part time
   Qualifications, relevant experience:
   Staff:

2. How is energy consumption reviewed?
   From head office or on location:
   Continuously or periodically:
   According to a plan or irregularly:

3 If periodically, when was the last review?
4. How is energy consumption analysed?
   By department;
   By product;
   By source;
   By month;
   By cost.

Between lighting, hot water, space heating, power, etc.
Between office, factory, warehouse, transport, etc.

5. Does analysis identify the relationship between consumption of energy and level of activity?
6. What units of measurement are used? (It may be useful to convert consumption of different sorts of energy into one unit — other than money.)
7. What are the metering control arrangements?
   (N.B. This question includes:
   How frequently are readings taken?
   To what extent is there submetering?
   What records are kept?)
   Coal or other solid fuels;
   Steam;
   Gas;
   Electricity;
   Liquid fuels;
   Water;
   Others;
8. Is there an energy consumption forecast/budget?
9. Have standards been set — i.e. standard energy consumption for each process or building?
10 Is consumption compared with:
   — previous periods?
   — other locations?
   — other companies?
   — other industries?
11. Has the management set targets:
   — for absolute levels of consumption?
   — for levels of consumption based on activity?
   — for levels of idle time?
   — for % cuts in consumption?
12. (a) Does management consider information on energy consumption an essential part of the management information system?
   (b) If not, why?
13. What steps have been taken by way of education of employees, to promote energy conservation?
14. What steps are being/have been taken in recycling energy —
   e.g. sale of by-products or scrap (having intrinsic energy content)?
   — reclamation of energy as heat from air, water, hot products etc?
   — recovery of heat from incineration of waste?
15. To what extent is planned maintenance in operation?
16. How often are different classes of plant inspected or tested —
   e.g. for corrosion, cracking, fouling, leaks, malfunctioning steam traps, inaccurate or inoperative control devices?
17. Who controls capital spending budget?
18. (a) Is there a list of energy saving investments under review, ranked in order of priority, with detailed costing and pay-back calculation?
   (b) If not, why?
19. Has a Sankey diagram been prepared? (Fig. 3)

### B. Sources of Energy

1 What are the sources of energy used?
   Coal or other solid fuels;
   Gas;
   Electricity;
   Liquid fuels;
   Others:
2. (a) What tariffs are used?
   (b) Why?
   (c) When were they last reviewed?

## C. Uses of Energy

1. Storage.
   - (a) How are storage tanks heated?
   - (b) Are they kept at most economic temperature?
   - (c) Are they adequately insulated?
2. What are areas of high energy consumption?
3. Is there any risk/evidence of unauthorised use or leakage?
4. What further steps are being considered to optimise savings and profits?
5. Processes:
   - (a) Are pipes and tanks adequately lagged?
   - (b) Is condensate recovered?
   - (c) Is boiler and furnace efficiency tested?
   - (d) Are process temperatures at lowest essential level?

# II. General Audit Programme

## A. Records of consumption

1. Produce detailed analysis of energy consumed over the most recent year. Show the amount, and cost per unit, of each fuel. (This will be used for the purpose of the current audit and for providing a baseline for comparison with later years).
2. Review existing records of consumption and determine if adequate information is available to management.
3. Draw Sankey Diagram (See Fig. 3).
4. Compare consumption with:
   - (a) Other locations
   - (b) Previous periods
   - (c) Budget
5. Compare standard consumption to actual for each process, and identify losses.
6. Test meter readings against records.
7. Test records against invoices.

## B. Housekeeping

1. Check that all control mechanisms are effective and frequently tested.
2. Consider whether further instruments would be useful in measuring or controlling particular parameters (e g. temperature, pressure, humidity, flow rate).
3. Determine whether maintenance is adequate (e.g. annual cleaning of boilers is unlikely to be sufficient to avoid fouling and corrosion of tubes).
4. Consider how maintenance could be improved;
   - — more skilled manpower,
   - — design change (e.g. fitting of by-pass facilities, pipe line strainers, sight glasses of steam traps etc.)
5. Review fuel storage and handling.
   - — consider whether temperatures are adequate or excessive.
   - — consider whether vapourisation could be reduced (e.g. by reducing the vapour space above volatile liquids).
6. Review space heating/cooling:
   - — check that the installation has fast response to control.
   - — check that control devices are protected from unauthorised interference.
   - — check that temperature, air movement and ventilation are not excessive.
   - — ensure windows are not used for temperature control in heated buildings.
   - — check insulation throughout.

     plant, including tanks and pipe runs,
     roofs,
     walls,
     doors, windows,
     floors, etc
   - — check that systems are properly integrated (i.e. boiler and refrigerator plants do not conflict).
   - — review heating installation.

     (NB: The purpose of this audit step, in conjunction with (A) above, is to determine when and how much heat is lost, with a view to recommending remedial action, if appropriate)
7. Review lighting:
   - — consider if the most efficient form of lighting is used for each purpose.
   - — check lighting levels maintain proper illumination.
8. Review tariffs or contracts for supply of energy:
   - — ensure the most appropriate tariffs are used, discuss with suppliers, if appropriate.
9. Check all reasonable steps are taken to minimise peak demands for electricity e.g.:
   - — re-schedule tasks to off-peak periods.
   - — use an emergency type diesel generator as booster/ alternative to electricity, preferably including waste heat recovery.
   - — monitor consumption precisely.
   - — use maximum demand meter.
10. Consider the feasibility of using night rate electricity.
11. Consider sub-metering, so that consumption can be broken down into controllable units, i.e. cost centres, thereby making some individual personally responsible.

## C. Personnel

1. Consider if specialist workers are adequately trained and motivated, e.g.:

   - energy manager,
   - maintenance engineer,
   - instrument engineer.
   - furnace operator,

2. Review energy conservation propaganda or education, e.g..

   - posters,
   - house magazines,
   - circulars,
   - requests for suggestions from employees,
   - talks and short courses,
   - involvement of unions.

## D. Capital Investment

1. Review energy related capital projects under consideration:

   - check calculation of return/pay-back,
   - review arguments for and against making the investment,
   - check that tax implications are correctly taken into account.

2. Review efficiency of furnaces, boilers and process equipment.

   (NB.:About 86 per cent of all energy used by industry is converted in boilers or furnaces)
   - Consider whether they should be replaced (advantage of PCRA boiler replacement scheme could be taken ).
   - Consider whether they should be modified:
     by pre-heating air,
     by adding metering facilities,
     by recovering waste heat,
     by improved insulation,
     by replacing burners (Modern burners have improved turndown capability which can be useful if there is a fluctuating load/demand and can show a 30 per cent return on capital),
     by adding economisers,
     by returning condensate to boilers,
   - consider the size of equipment vis-a-vis demand.
   - determine whether use of cooling water is restricted to an economic level.

Appendix - II

# CONVERSION FACTORS AND ENERGY UNITS

1 Btu = 1.055 K. Joules
1 Btu/lb = 0.002326 MJ/Kg.
1 MJ/Kg. = 429.9 Btu/lb.
1 therm. = 100,000 Btu = 29.3 KWH = 105.5 MJ
1 megajoule = 947.8 Btu = 0.2778 KWH
= 0.009478 therm.
1 cu.ft. = 0.02832 cu.m.
1 cu. metre = 35.315 c.ft.
1 MJ/cu.m. = 26.84 Btu/cu.ft.
1 Kwh = 3.6 Mje = 860 K.cal.

# ABBREVIATIONS

| | |
|---|---|
| K (Kilo) | — $10^3$ (thousan |
| M (Mega) | — $10^6$ (million) |
| G (Giga) | — $10^9$ (billion) |
| T (Tera) | — $10^{12}$ (trillion) |
| P (Peta) | — $10^{15}$ |
| E (Exa) | — $10^{18}$ |

# ENERGY FORM AND CONVERSION TO GJ:

a. Electricity (KWH) = 0.0036 GJ
b. Fuel oil (tonnes) = 43.73 GJ
C. Industrial diesel oil (tonnes) = 45.5 GJ
d. Automotive distillate (litres) = 0.0383 GJ
e. Kerosene (litres) = 0.0375 GJ
f. LPG (tonnes) = 50.3 GJ
(litres) = 0.0266 GJ
g. Coal (Black) tonne = 30.7 GJ
(Brown) tonne = 9.7 GJ

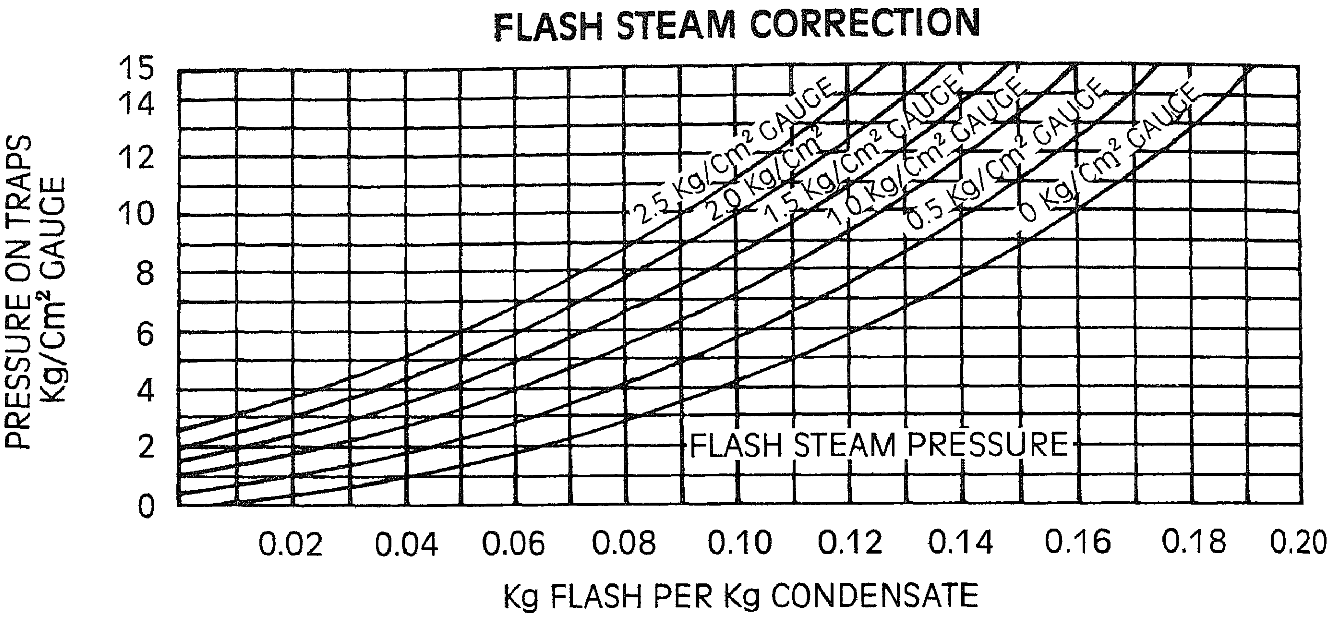


Fig.10

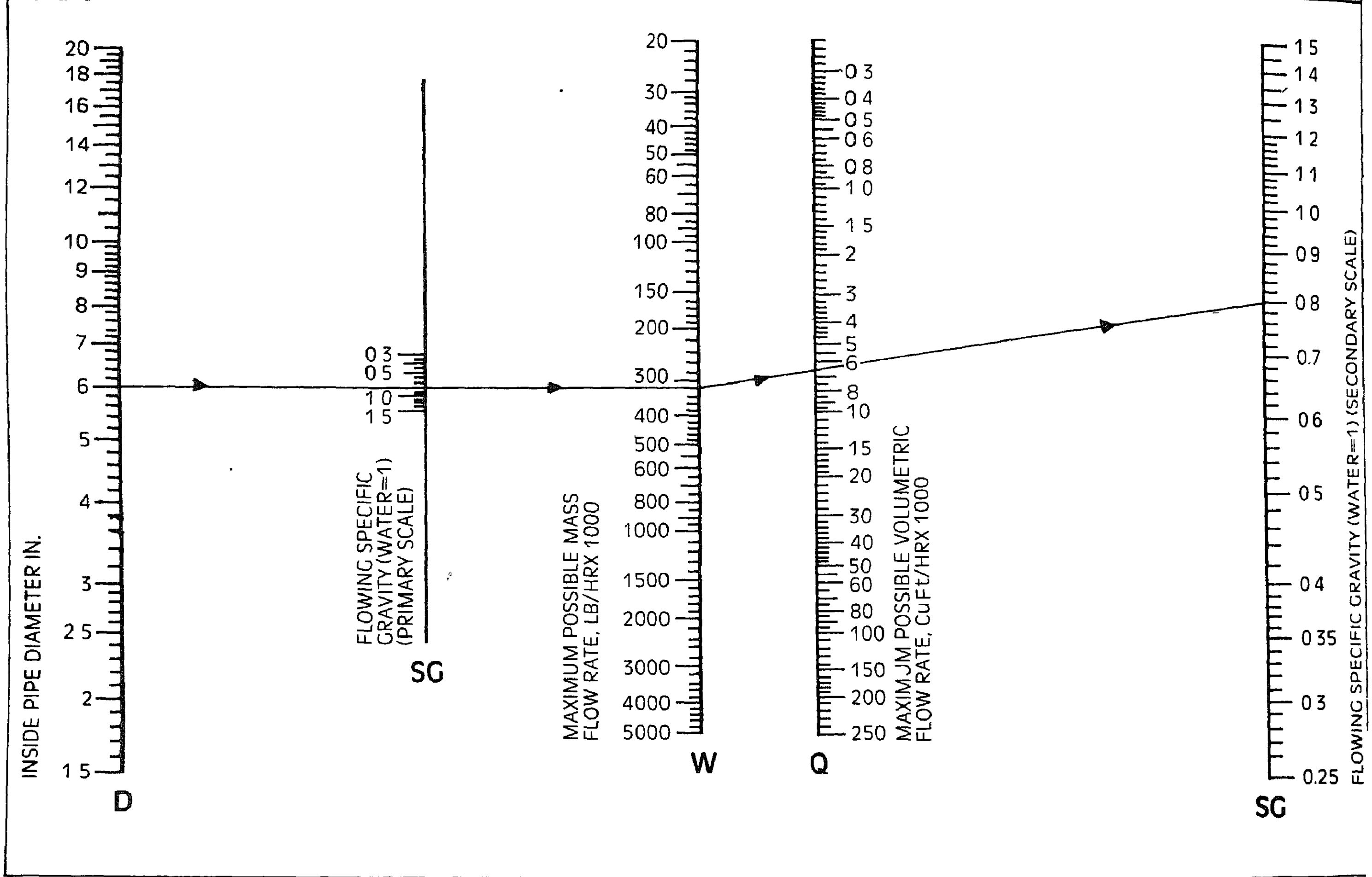
Flash steam is formed when there is a drop in condensate pressure — which, normally, is immediately after the steam trap orifice. Flash steam can be used locally which results in substantial savings. The amount of condensate re-evaporation to steam depends on the difference in pressure. The higher the initial pressure and the lower the flash recovery pressure, the greater will be the flash steam formed. The figure shown above gives the amount of flash steam available at different pressure levels.

# CAPACITY OF PIPELINES

**Table 2** Pipeline Capacities at Specific Velocities–Metric Units

| Pressure bar | Velocity m/s | kg/h<br>15 mm | 20 mm | 25 mm | 32 mm | 40 mm | 50 mm | 65 mm | 80 mm | 100mm | 125mm | 150mm |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.4 | 15 | 7 | 14 | 24 | 37 | 52 | 99 | 145 | 213 | 394 | 648 | 917 |
| | 25 | 10 | 25 | 40 | 62 | 92 | 162 | 265 | 384 | 675 | 972 | 1457 |
| | 40 | 17 | 35 | 64 | 102 | 142 | 265 | 403 | 576 | 1037 | 1670 | 2303 |
| 0.7 | 15 | 7 | 16 | 25 | 40 | 59 | 109 | 166 | 250 | 431 | 680 | 1006 |
| | 25 | 12 | 25 | 45 | 72 | 100 | 182 | 287 | 430 | 716 | 1145 | 1575 |
| | 40 | 18 | 37 | 68 | 106 | 167 | 298 | 428 | 630 | 1108 | 1712 | 2417 |
| 1.0 | 15 | 8 | 17 | 29 | 43 | 65 | 112 | 182 | 260 | 470 | 694 | 1020 |
| | 25 | 12 | 26 | 48 | 72 | 100 | 193 | 300 | 445 | 730 | 1160 | 1660 |
| | 40 | 19 | 39 | 71 | 112 | 172 | 311 | 465 | 640 | 1150 | 1800 | 2500 |
| 2.0 | 15 | 12 | 25 | 45 | 70 | 100 | 182 | 280 | 410 | 715 | 1125 | 1580 |
| | 25 | 19 | 43 | 70 | 112 | 162 | 295 | 428 | 656 | 1215 | 1755 | 2520 |
| | 40 | 30 | 64 | 115 | 178 | 275 | 475 | 745 | 1010 | 1895 | 2925 | 4175 |
| 3.0 | 15 | 16 | 37 | 60 | 93 | 127 | 245 | 385 | 535 | 925 | 1505 | 2040 |
| | 25 | 26 | 56 | 100 | 152 | 225 | 425 | 632 | 910 | 1580 | 2480 | 3440 |
| | 40 | 41 | 87 | 157 | 250 | 357 | 595 | 1025 | 1460 | 2540 | 4050 | 5940 |
| 4.0 | 15 | 19 | 42 | 70 | 108 | 156 | 281 | 432 | 635 | 1166 | 1685 | 2460 |
| | 25 | 30 | 63 | 115 | 180 | 270 | 450 | 742 | 1080 | 1980 | 2925 | 4225 |
| | 40 | 49 | 116 | 197 | 295 | 456 | 796 | 1247 | 1825 | 3120 | 4940 | 7050 |
| 5.0 | 15 | 22 | 49 | 87 | 128 | 187 | 352 | 526 | 770 | 1295 | 2105 | 2835 |
| | 25 | 36 | 81 | 135 | 211 | 308 | 548 | 885 | 1265 | 2110 | 3540 | 5150 |
| | 40 | 59 | 131 | 225 | 338 | 495 | 855 | 1350 | 1890 | 3510 | 5400 | 7870 |
| 6.0 | 15 | 26 | 59 | 105 | 153 | 225 | 425 | 632 | 925 | 1555 | 2525 | 3400 |
| | 25 | 43 | 97 | 162 | 253 | 370 | 658 | 1065 | 1520 | 2530 | 4250 | 6175 |
| | 40 | 71 | 157 | 270 | 405 | 595 | 1025 | 1620 | 2270 | 4210 | 6475 | 9445 |
| 7.0 | 15 | 29 | 63 | 110 | 165 | 260 | 445 | 705 | 952 | 1815 | 2765 | 3990 |
| | 25 | 49 | 114 | 190 | 288 | 450 | 785 | 1205 | 1750 | 3025 | 4815 | 6900 |
| | 40 | 76 | 177 | 303 | 455 | 690 | 1210 | 1865 | 2520 | 4585 | 7560 | 10880 |
| 8.0 | 15 | 32 | 70 | 126 | 190 | 285 | 475 | 800 | 1125 | 1990 | 3025 | 4540 |
| | 25 | 54 | 122 | 205 | 320 | 465 | 810 | 1260 | 1870 | 3240 | 5220 | 7120 |
| | 40 | 84 | 192 | 327 | 510 | 730 | 1370 | 2065 | 3120 | 5135 | 8395 | 12470 |
| 10.0 | 15 | 41 | 95 | 155 | 250 | 372 | 626 | 1012 | 1465 | 2495 | 3995 | 5860 |
| | 25 | 66 | 145 | 257 | 405 | 562 | 990 | 1530 | 2205 | 3825 | 6295 | 8995 |
| | 40 | 104 | 216 | 408 | 615 | 910 | 1635 | 2545 | 3600 | 6230 | 9880 | 14390 |
| 14.0 | 15 | 50 | 121 | 205 | 310 | 465 | 810 | 1270 | 1870 | 3220 | 5215 | 7390 |
| | 25 | 85 | 195 | 331 | 520 | 740 | 1375 | 2080 | 3120 | 5200 | 8500 | 12560 |
| | 40 | 126 | 305 | 555 | 825 | 1210 | 2195 | 3425 | 4735 | 8510 | 13050 | 18630 |

# FLOW RATE THROUGH PIPE



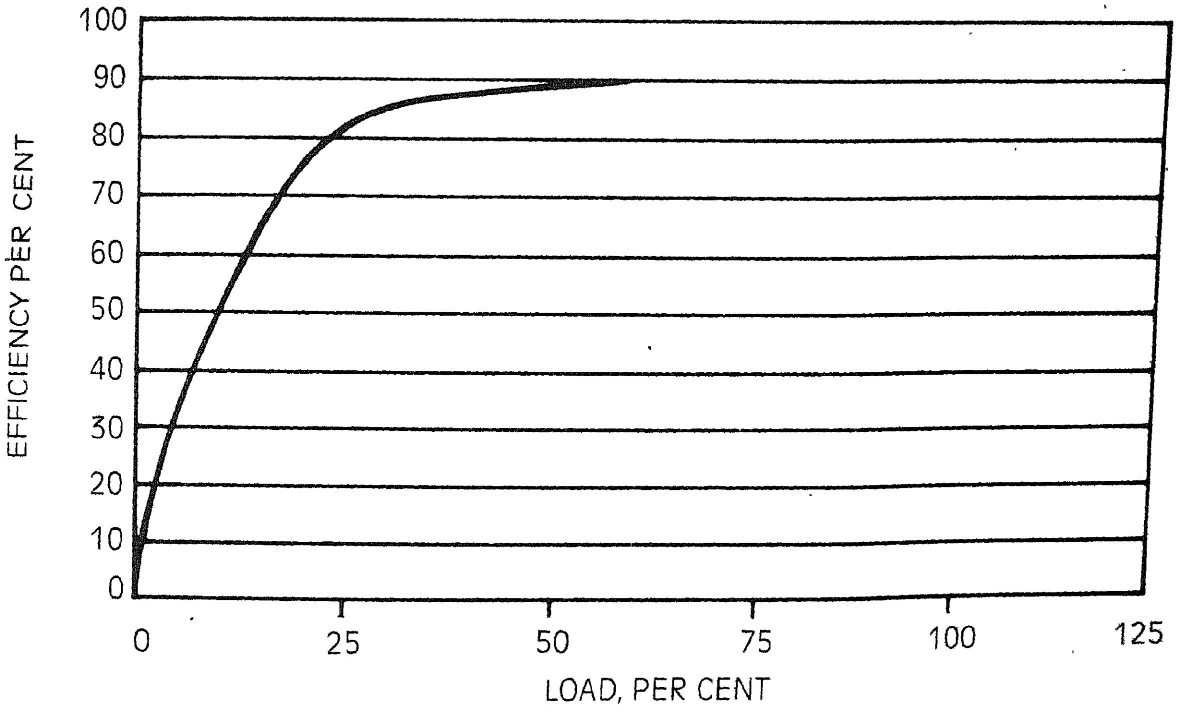
This nomograph is made in two parts. Left hand side provides the maximum possible mass flow rates and the right hand side gives the maximum possible volume flow rates of liquids, the volume being measured at the specific flow conditions

**Problem:**
Find the maximum flow rate possible when a liquid with a specific gravity of 0 8 is flowing through a pipe having an internal diameter of 6 inches.

**Solution:**
Use a straightedge to connect 6 on scale with 0.8 on primary scale SG and extend the line to intersect scale W, reading the maximum flow rate as 32,000 lb/hr. Connect 320,000 on scale W with 0.8 on secondary scale SG and where scale Q is crossed, read the maximum possible volume flow rate as 6400 cu.ft/hr.

Appendix - VI

## MOTOR EFFICIENCY AS A FUNCTION OF LOADING



Each motor has a unique efficiency curve, but motor efficiency curves in general adhere to the shape shown here Manufacturers generally design their motors for maximum efficiency at or about 100 per cent of full load If efficiency of one motor is being compared to that of another, and specific efficiency curves are not available for both, it can be reasonably presumed that the general shape of the curves for both motors will conform to the shape shown here, although magnitudes might differ.

Appendix - VII

**REFERENCE :**

1. Energy Auditing — Published by the Fairmont Press Inc P.O. Box 14227 Atlanta, Georgia - 30324
2. Energy Analysis: A New Public Policy Tool — Edited by Martha W. Gilland.
3. Energy Audit Series — Department of Energy, London.
4. Spirax Sarco Information Book — Spirax Sarco Ltd., Cheltenham, London

The following PCRA booklets on Efficient Utilisation of Fuel Oils in Industry, are available :

1. Storage, handling and preparation of fuel oil
2. Combustion of fuel oils & Burners — operation and maintenance.
3. Efficient generation of steam
4. Efficient utilisation of steam.
5 Fuel economy in furnaces and waste heat recovery.
6. Refractories.
7. Thermal insulation.

PCRA films available for industrial sector

1. "Tuning of Boilers and Furnaces"
2. "Handling of Fuel Oils"
3. "Efficient Utilisation of Steam in industries" — (under production).

Set up a few years ago in anticipation of the world-wide oil crisis that is affecting us all today, PCRA seeks to promote efficient utilisation of petroleum products — in homes, in industries, in farms, on roads. Because till alternative sources of energy are found, we have to make the best use of the world's diminishing oil reserves.

P C R A

**Petroleum Conservation Research Association**

Petroleum Conservation Research
Association, 1008, New Delhi House,
27, Barakhamba Road, New Delhi - 110 001.

**SAVE OIL.**
**Because oil isn't going to last forever.**

# EFFICIENT OPERATION OF BOILERS AND FURNACES

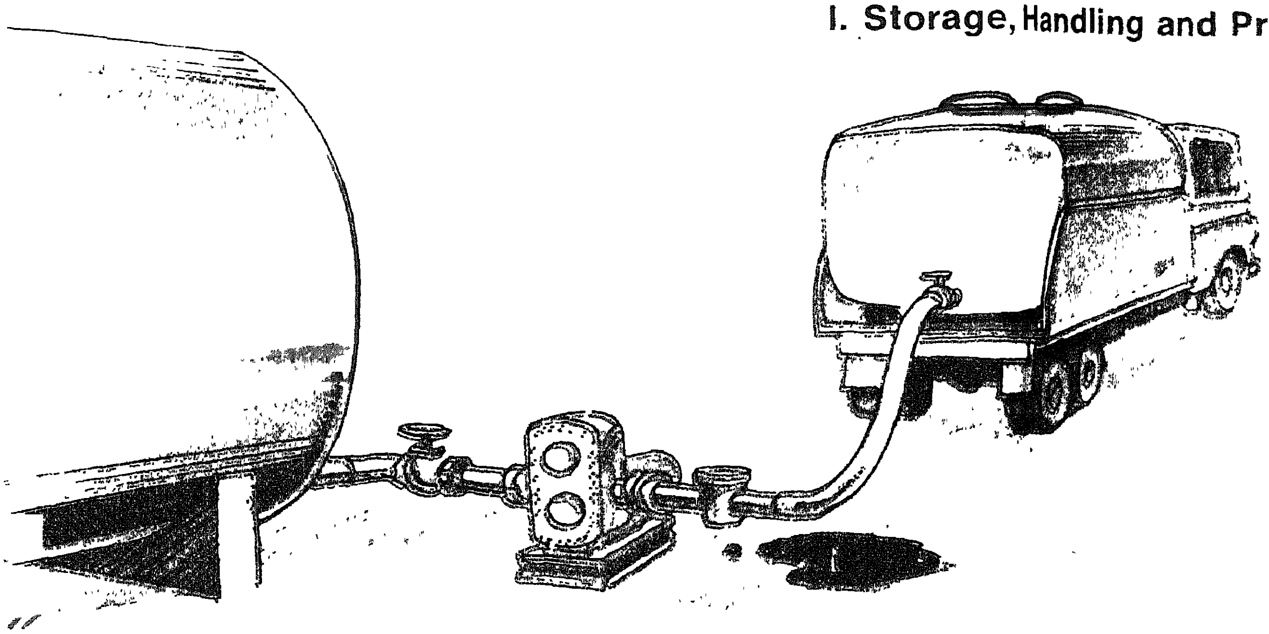
## AN OPERATOR'S GUIDE

# Introduction

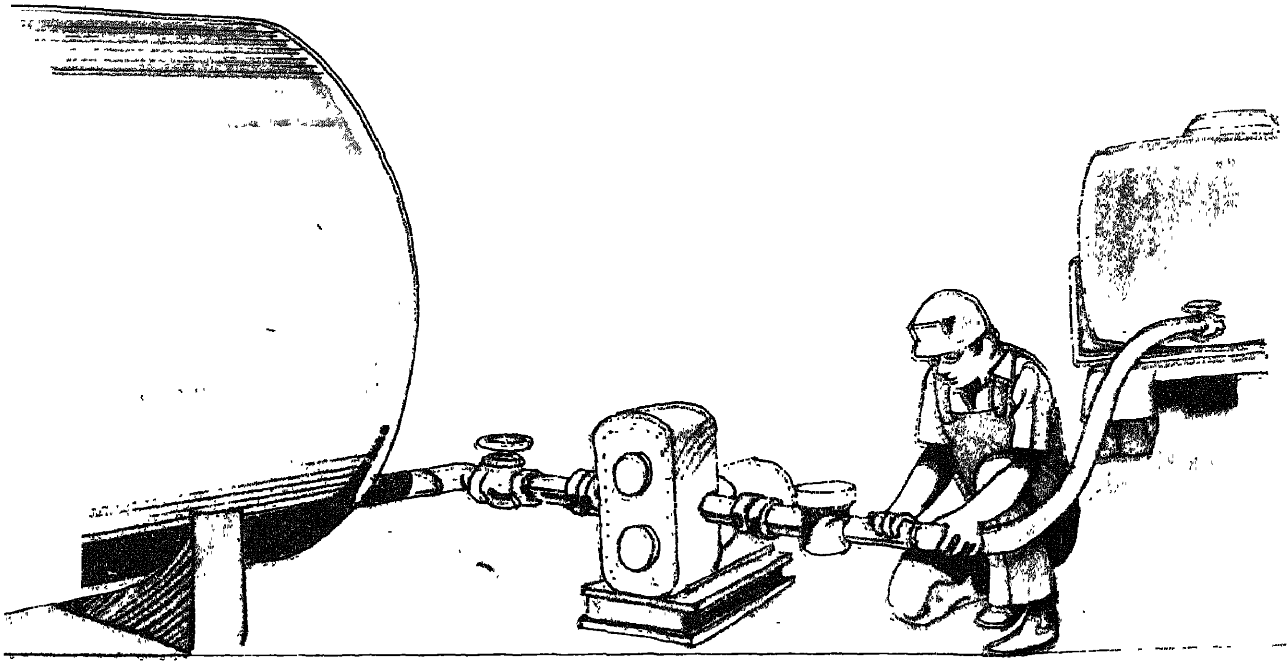
The efficiency of a boiler or furnace depends on how efficient the combustion system is and how best it is being operated. This involves following correct methods for efficient boiler and furnace operation

This booklet provides guidelines for proper operation and maintenance of boilers and furnaces and for a proper understanding of steam generation, distribution and utilisation

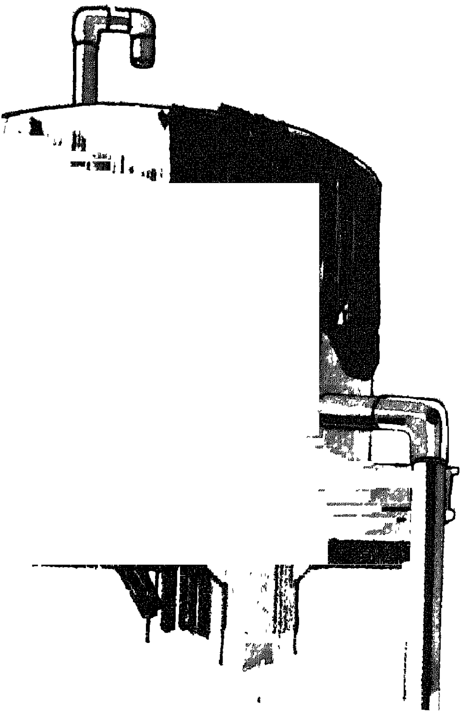
# I. Storage, Handling and Preparation of Fuel Oil

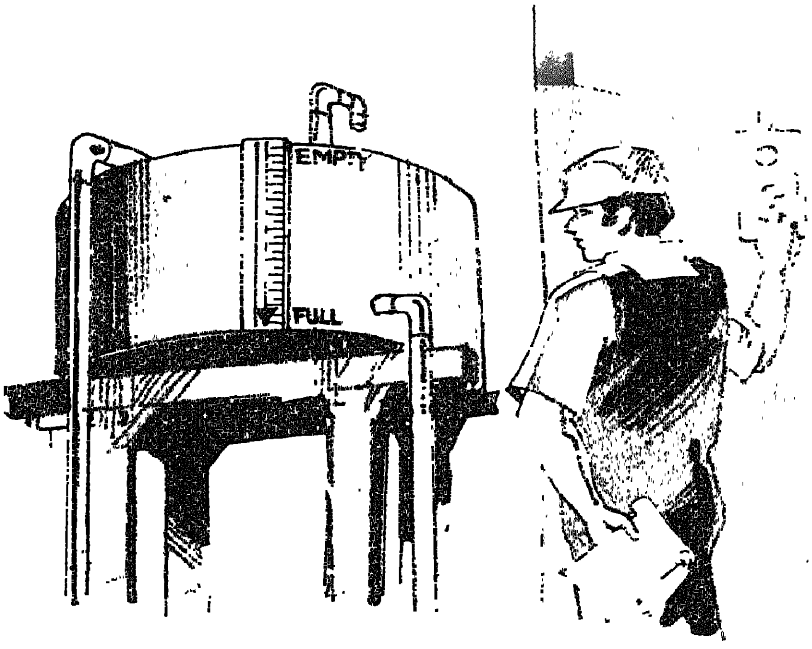


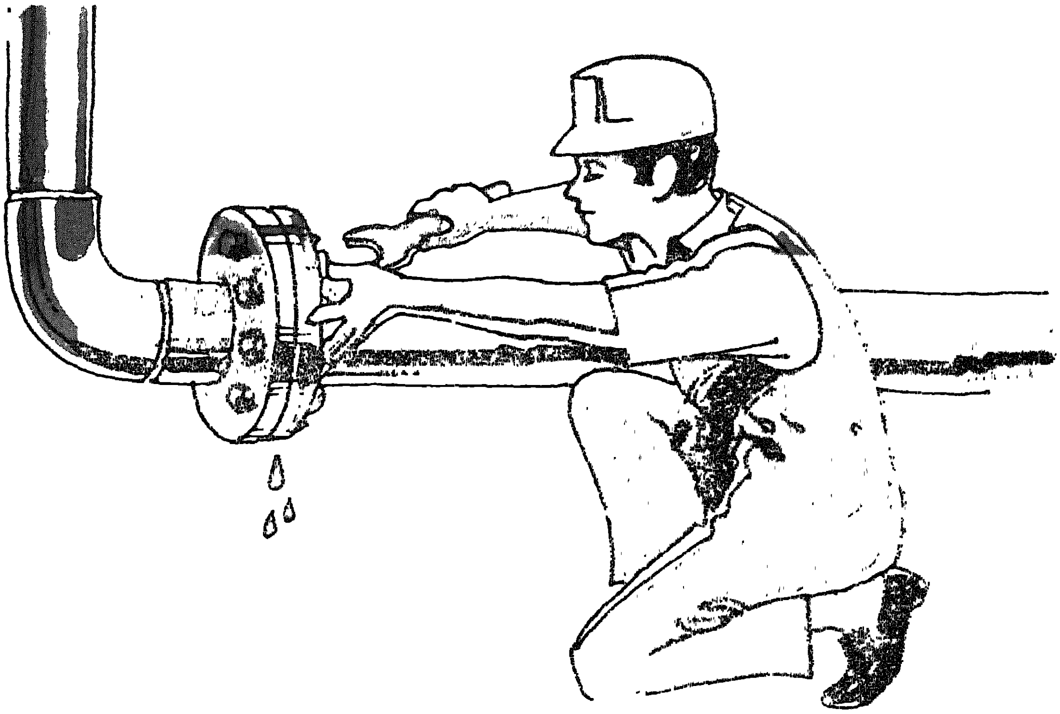
## 1. Avoid oil spillage



Tighten all hose connections to the storage tank at the decanting point and the pipe connections to the tank



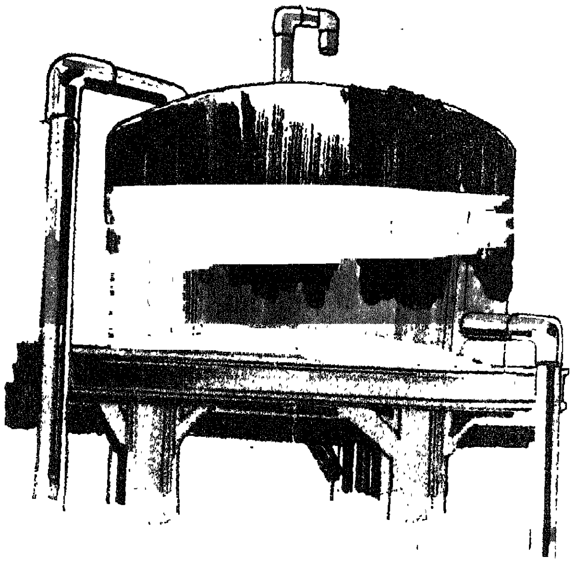

EMPTY
FULL

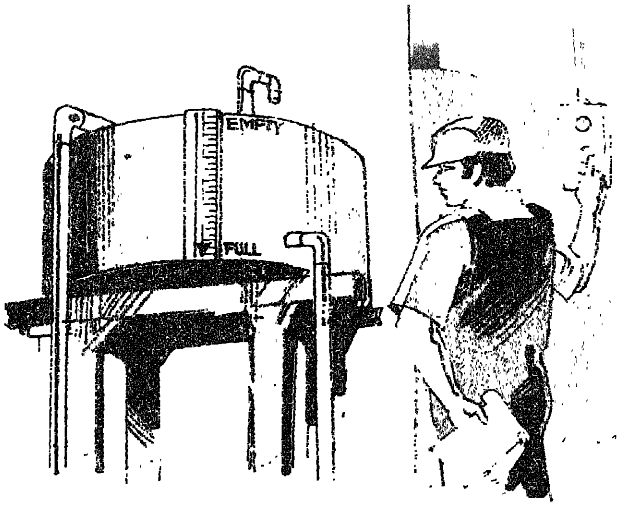


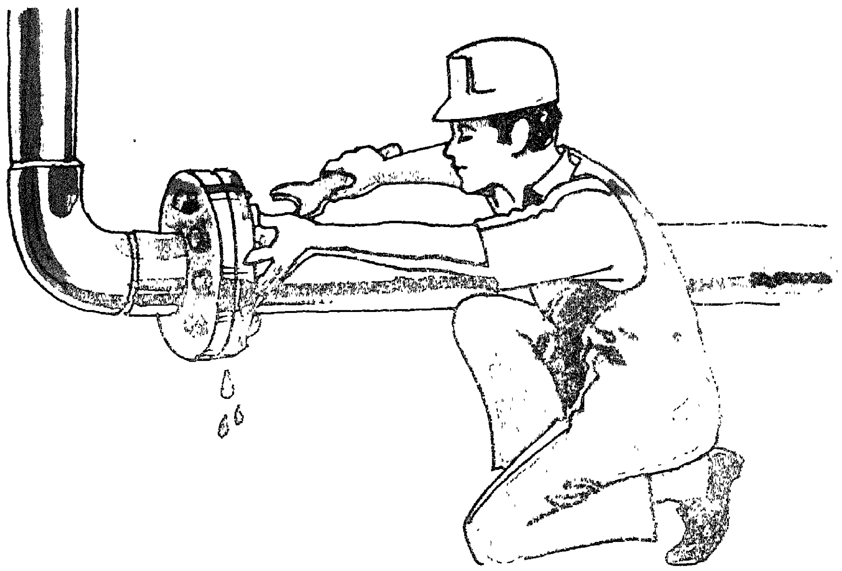
## 2. Prevent oil leakage

Stop oil leaks from flanges, valves, joints or pumps promptly. A leak of one drop every second amounts to a loss of over 4000 litres of oil per year.

When you fill the service tank, do not let the oil overflow.

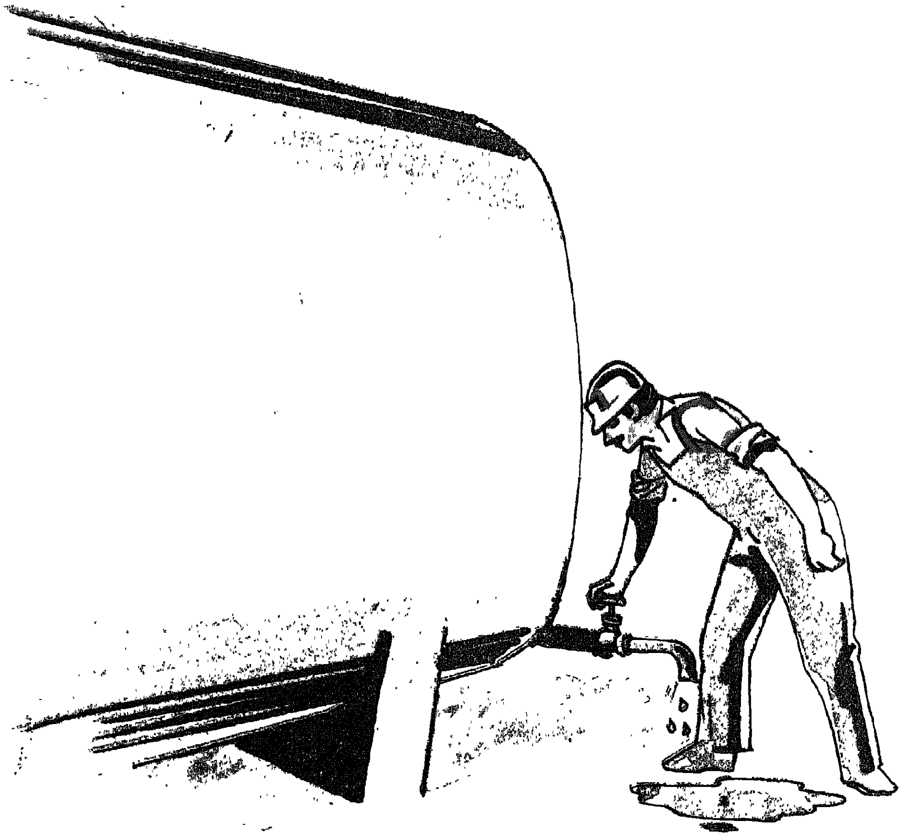






## 2. Prevent oil leakage

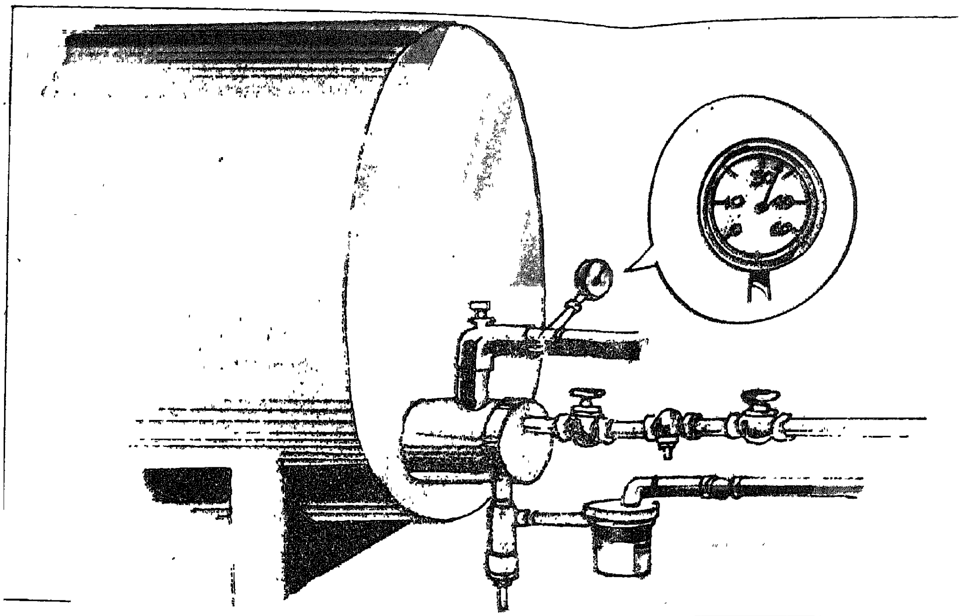
Stop oil leaks from flanges, valves, joints or bends promptly. A leak of one drop every second amounts to a loss of over 4,000 litres of oil per year



### 3. Drain water from storage tanks regularly

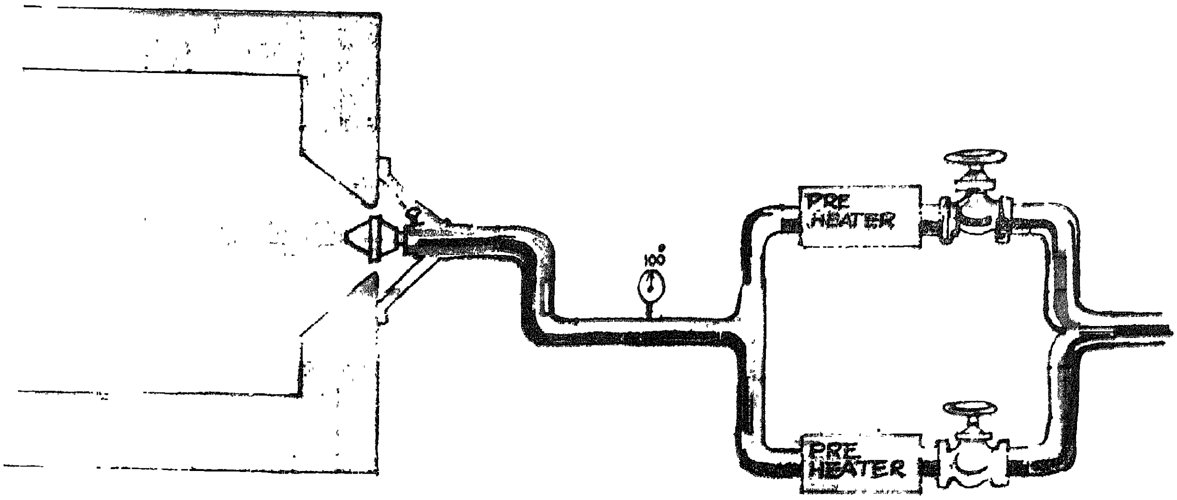
A thick, dirty sludge would form if water is allowed to remain mixed in oil. So drain off water from the storage tank periodically.

4. Clean oil filters periodically

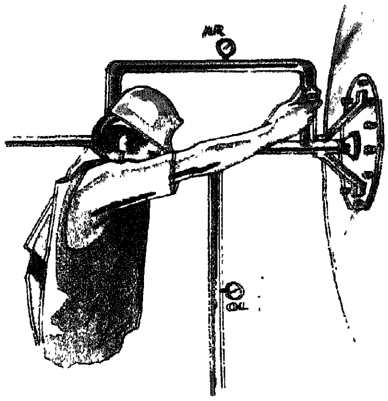


## 5. Maintain correct preheat temperature of oil

Use out-flow heater in the main storage tank only during winter. Take care to maintain the temperature between 30°-35°C for furnace oil.

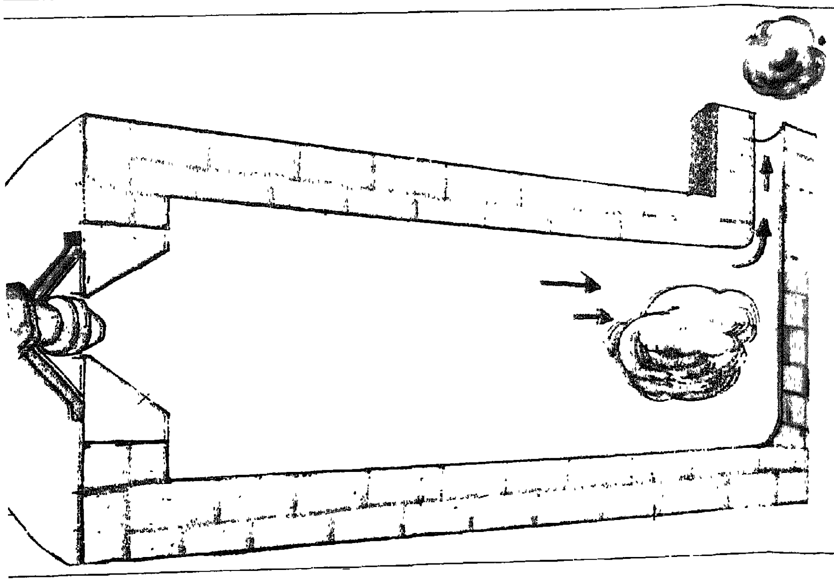


Before supplying furnace oil to the burner, it should be heated to about 100°C.



### 6. Maintain correct pressure of oil and air at burner

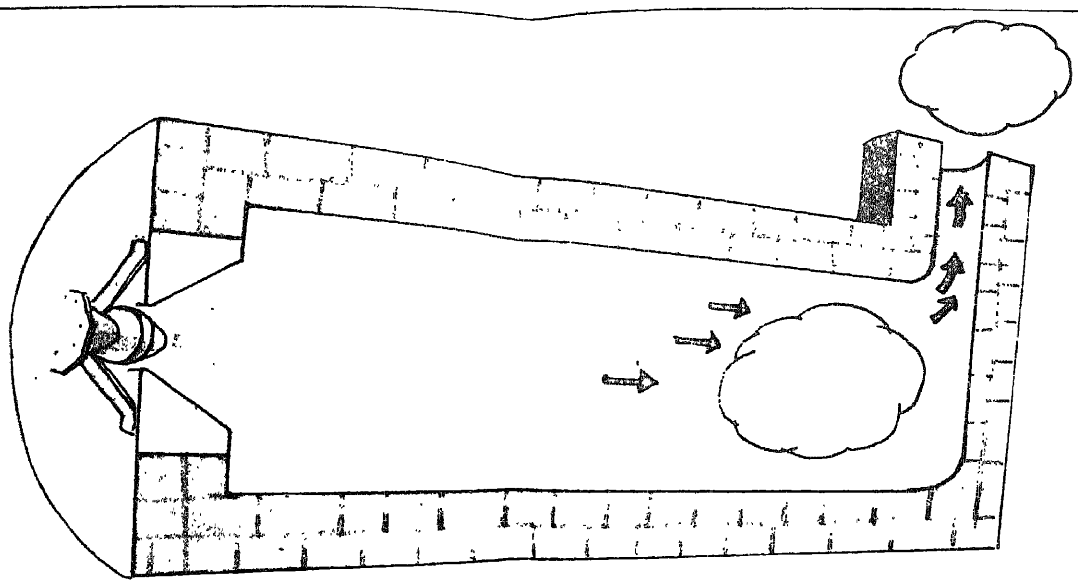
| **Burner type** | **Oil pressure** | **Air pressure** |
|---|---|---|
| LAP | 0.6-0.8 kg/cm$^2$ | 60 cm of water gauge |
| MAP | 6-7 kg/cm$^2$ | 2-3 kg/cm$^2$ |
| Pressure jet | 14-18 kg/cm$^2$ | — |



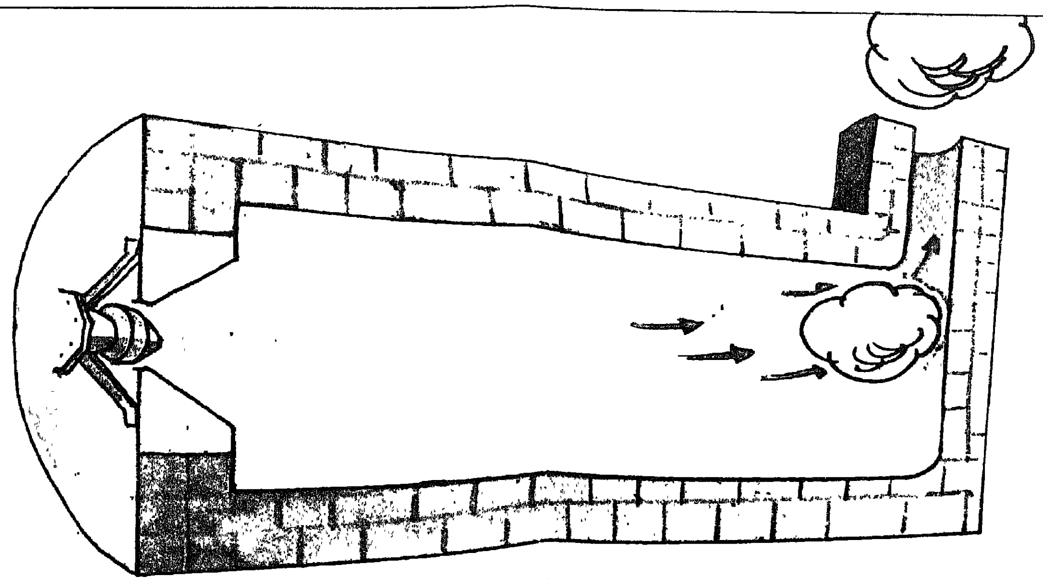
## II. Combustion and Burners

### 7. Smoke indicates combustion condition

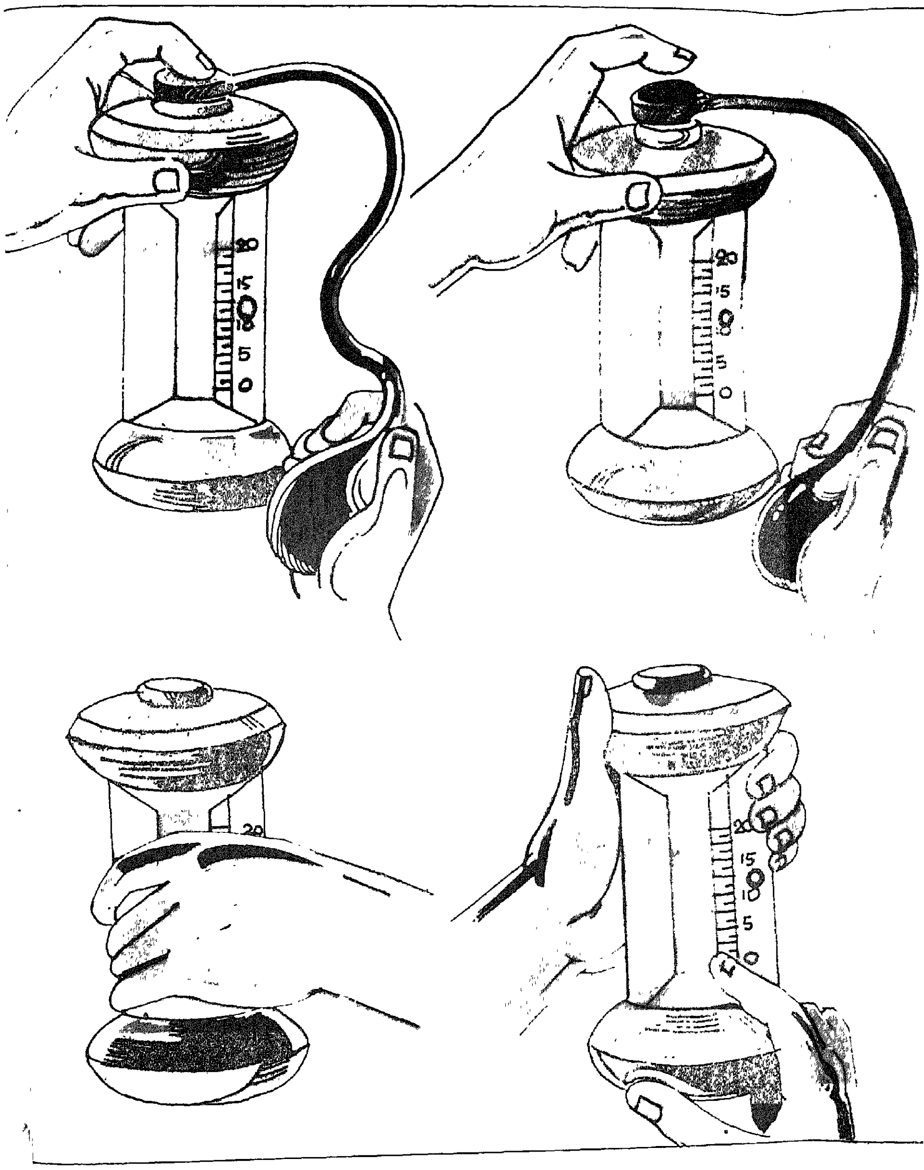
A lot of fuel is wasted when black smoke comes out from the chimney. This indicates poor combustion



A very clean chimney on the contrary, shows that too much air is being used for combustion.



The best combustion is achieved when you get a light brown haze from the chimney which shows the desired level of excess air

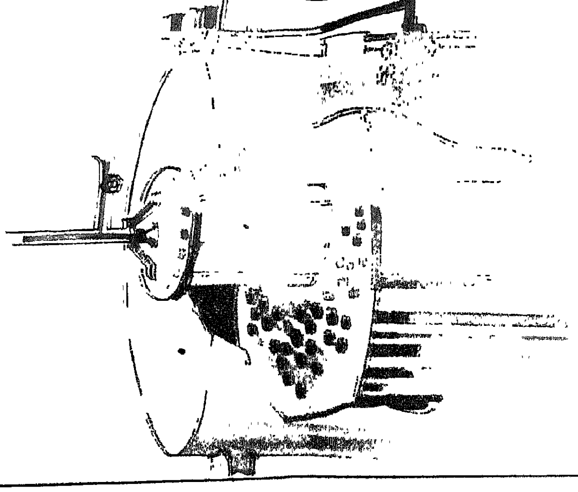


## 8. Reduce excess air

Theoretically, 1 kg. of oil requires 14.1 kg. of air for complete combustion. But in practice, about 20-25% excess air is required for complete combustion.

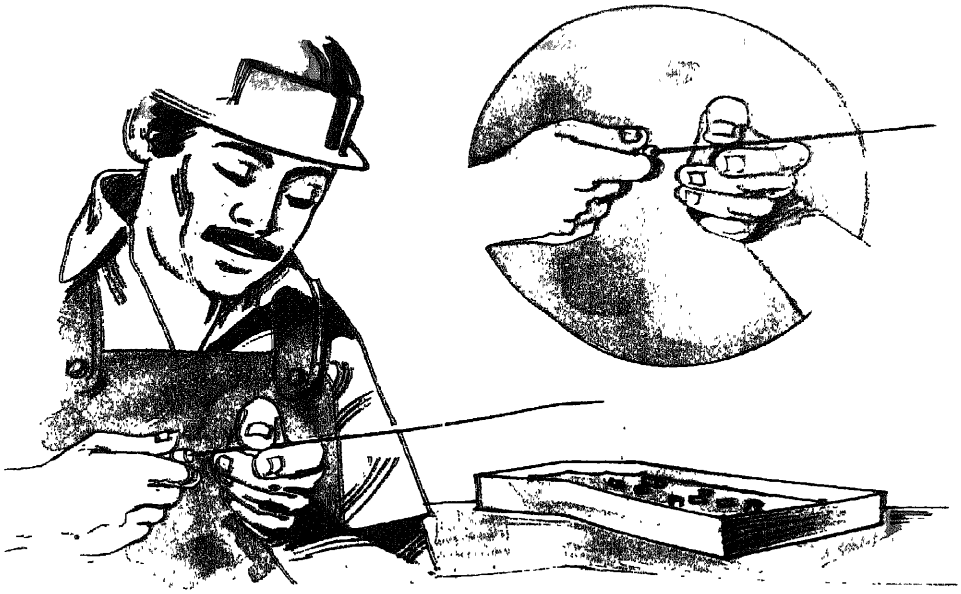
If the carbon-di-oxide is below 12.5% to 13% or if the oxygen is above 4% to 4.5%, it shows that there is more of excess air.

Excess air would make the burner use up more fuel. Analyse flue gases for carbon-di-oxide and oxygen content periodically.



## 9. Replace cracked burner blocks fast

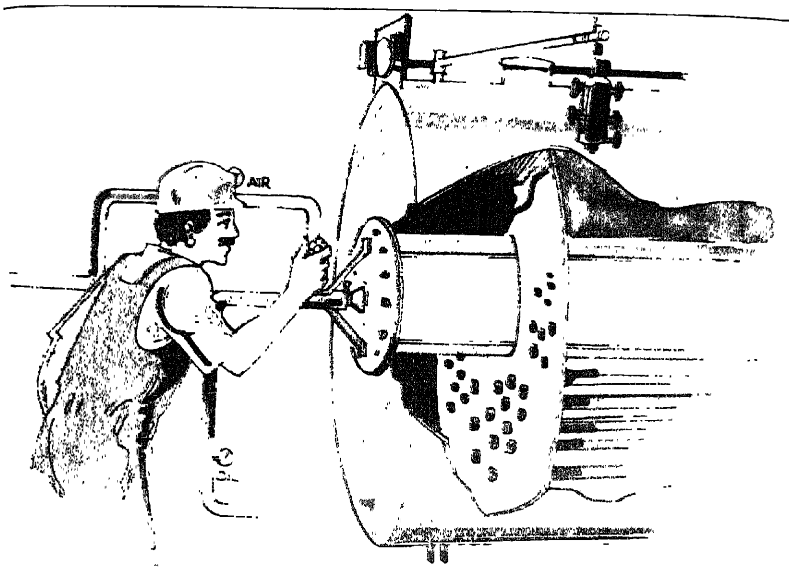
A cracked or damaged burner block will disturb the shape of the flame and result in poor combustion. This will also cause problems in restarting the furnace or boiler.



## 10. Clean burner nozzles regularly

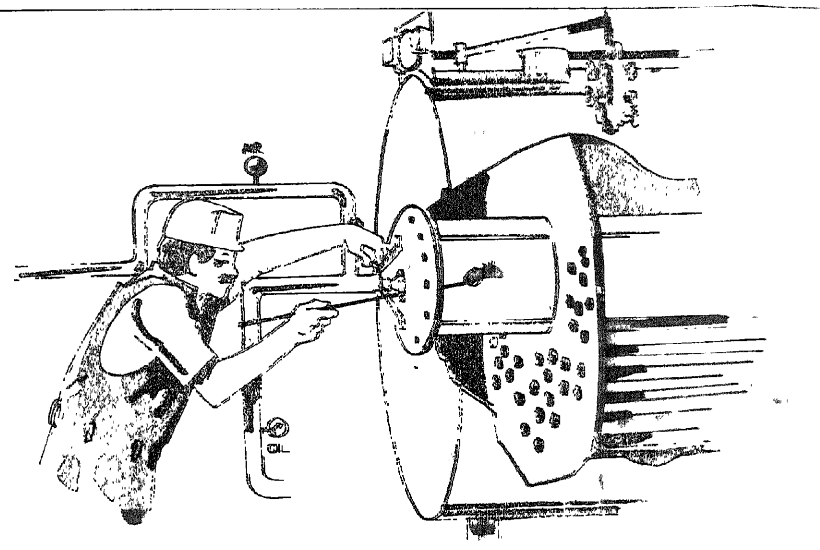
It is a good practice to clean burner nozzles at least once in a shift. First of all, soak the nozzles in kerosene and after a while, when deposits are well soaked, remove the carbon particles by rubbing them away. Use some soft wire like copper. Never use steel wire as this would damage the nozzles Always keep some spare nozzles handy

## 11. Follow correct methods for efficient boiler operation

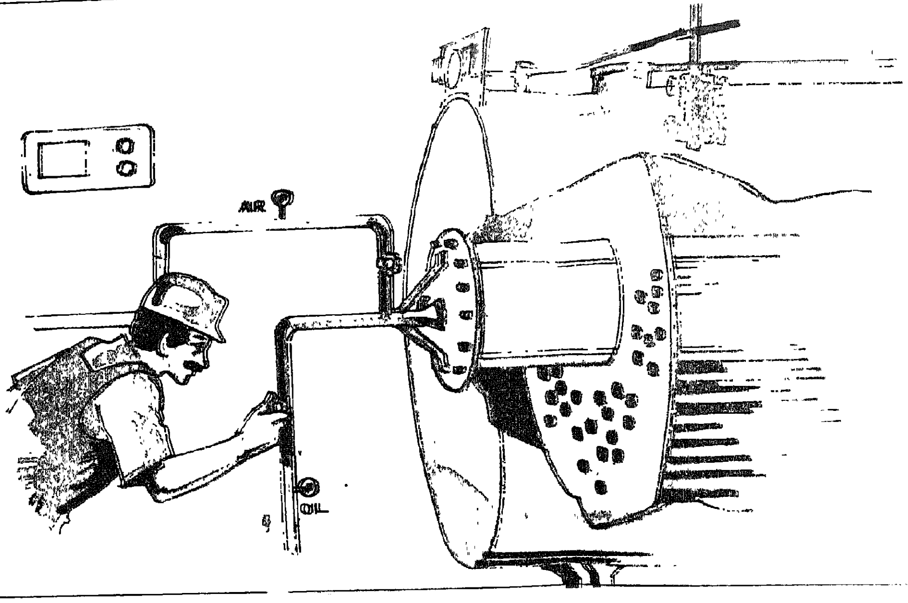


### (i) Start-up

Before lighting the burner, start the blower first and keep it running for some time to purge oil vapour/gases, if any

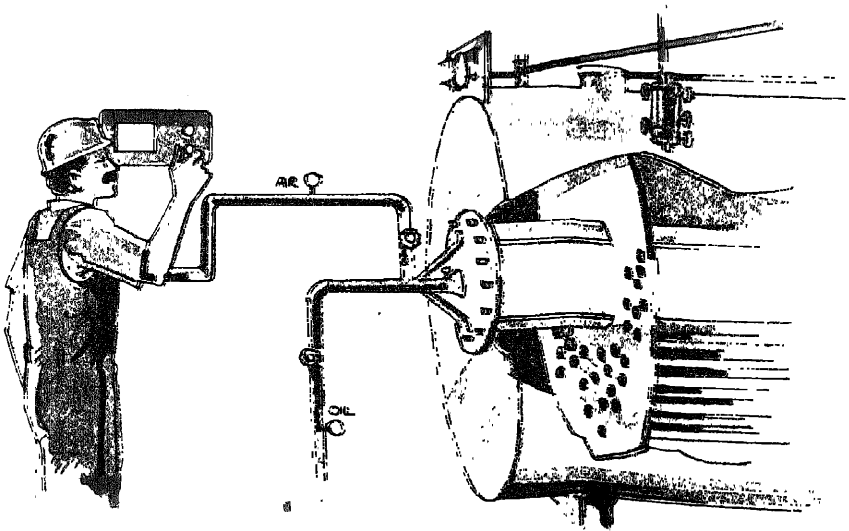


Take care to place the flame either from a torch or any other source only in front of the nozzle. Before lighting, ensure that only preheated oil reaches the burner

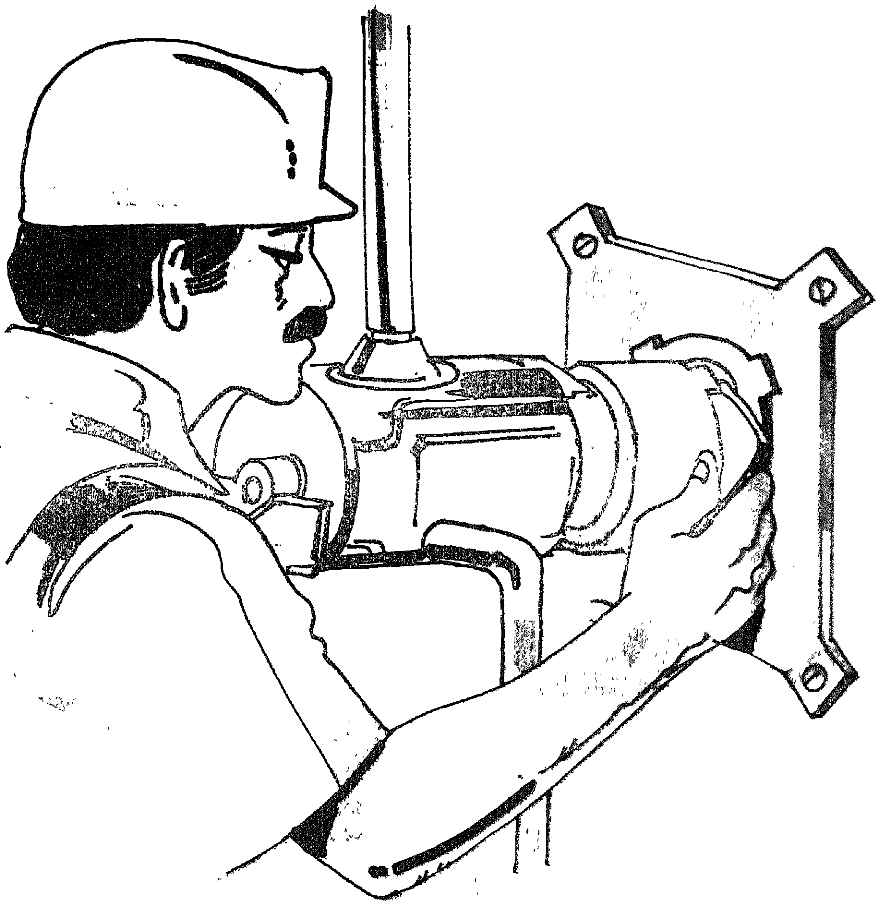


### (iv) Shut down

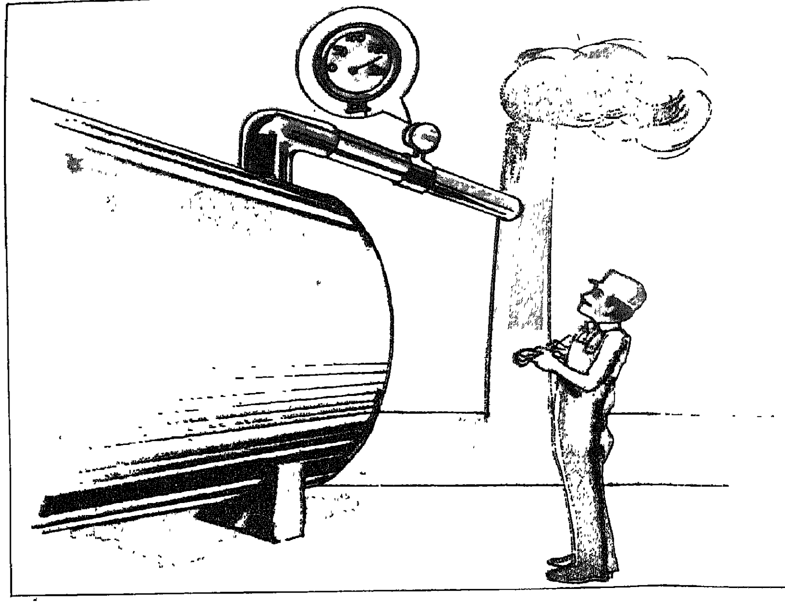
Close oil line first.



Purge the oil vapour by keeping the blower on for sometime.

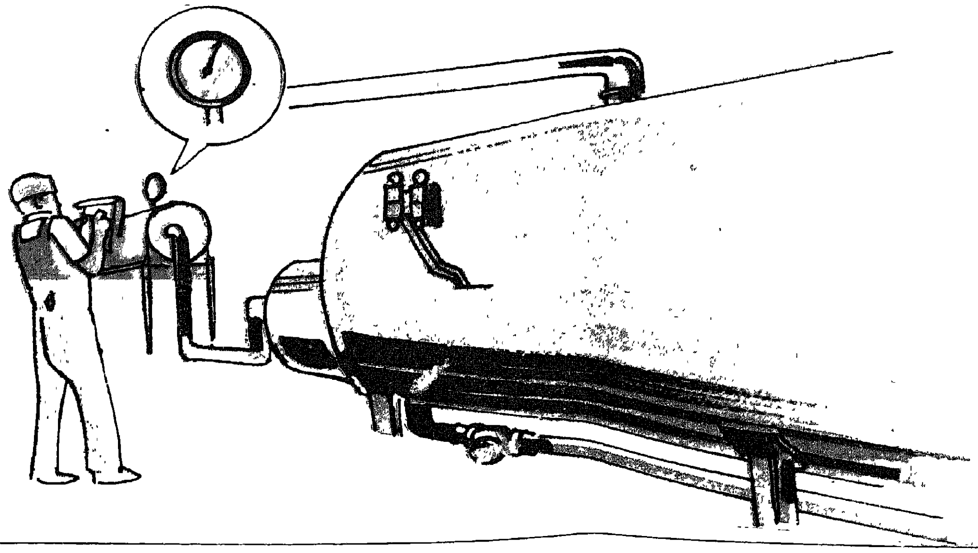


Do not keep the burner nozzle exposed to the radiant heat of the furnace. When you shut off the oil, take care to remove the burner/nozzle or place a thin refractory between the nozzle and the furnace.



## 15. Analyse flue gases regularly

Flue gases need to be analysed frequently. Always maintain 12.5% to 13% carbon-di-oxide or 4-5% oxygen.
If the flue gas tamperature rises about 40°C above the required normal (i.e. 180-200°C), then it should be reported immediately, for it is a sign of soot deposition. Even a soot of 3 mm thickness on the heat transfer surface can increase your fuel consumption by as much as 2 to 5%



## 16. Check feed water temperature

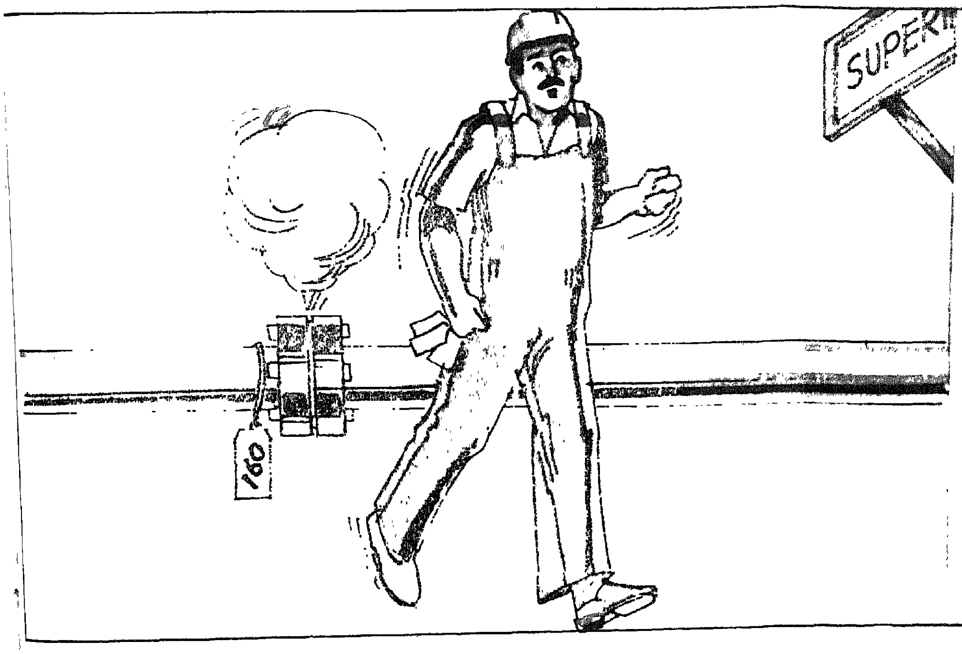
A sudden increase in feed water temperature is not normal and may result in damaging the feed water pump. Check feed water temperature frequently. Report wide variations promptly.

## IV. Steam Distribution

### 17. Is the steam distribution in order?

Check and report the following:

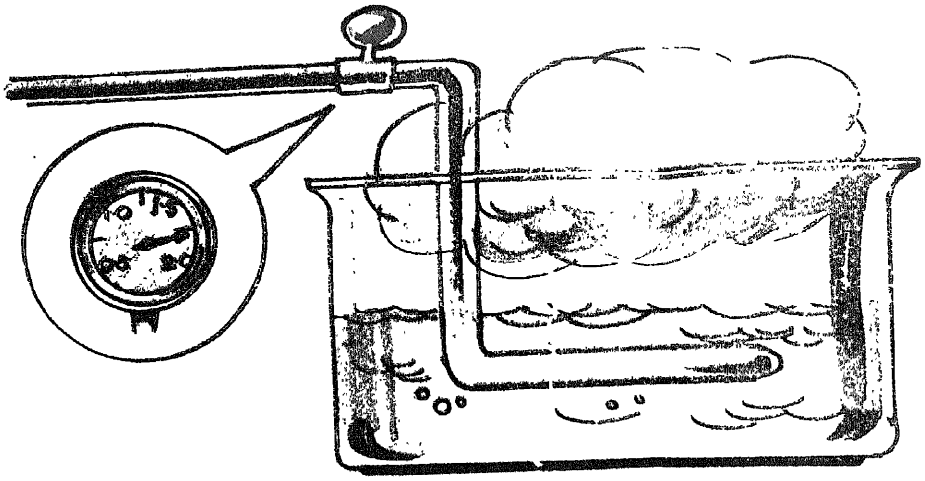
a) Steam leak  
b) Sagged pipelines  
c) Damaged insulation of pipelines, flanges and joints.



## V. Efficient Steam Usage

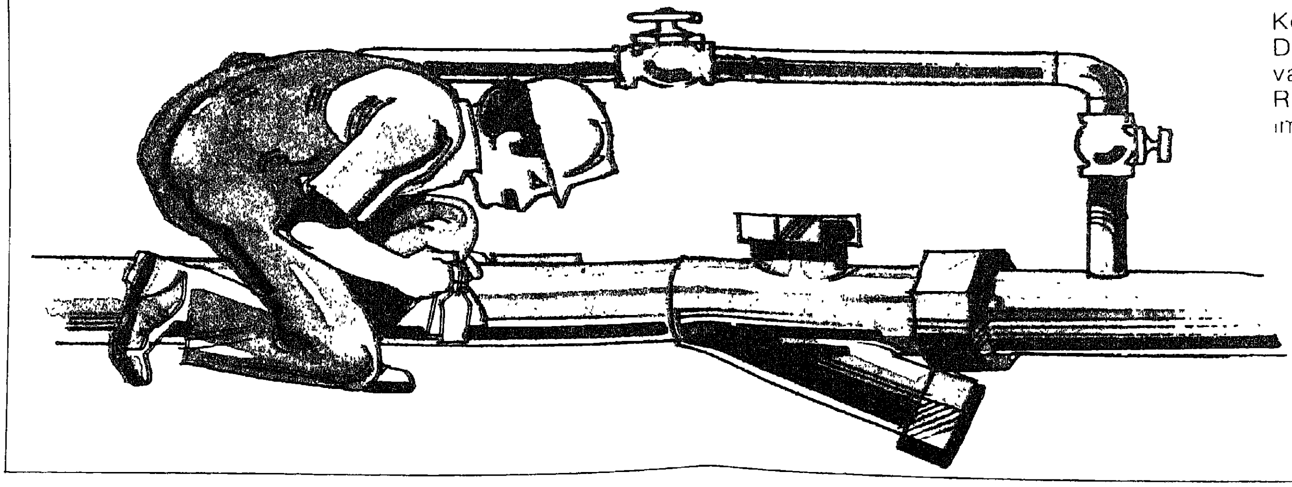
### 18. Stop steam leakages

Attend to steam leak promptly  
A 3mm diameter leak on a pipeline carrying 7kg/cm$^2$ steam would amount to a waste of 32,000 litres of furnace oil per year



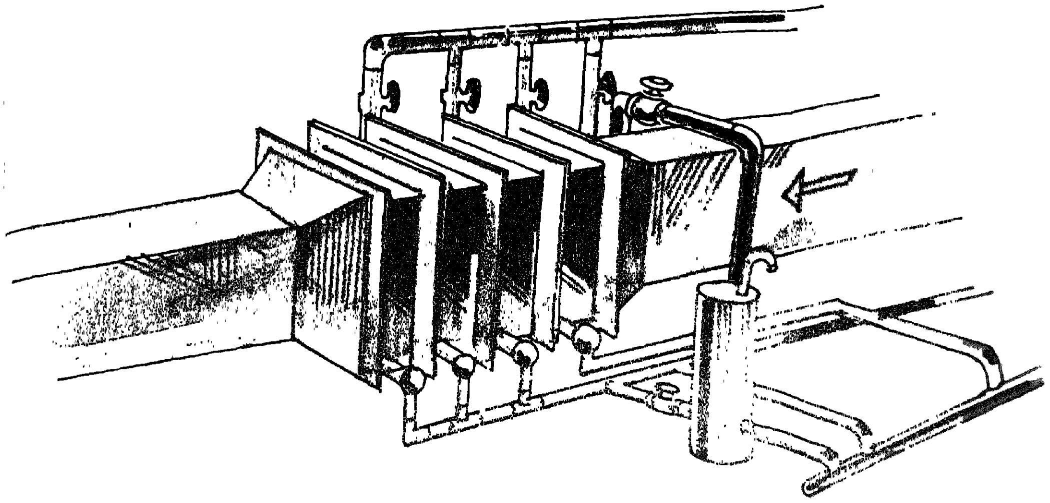
## 19. Use right quality steam

Use dry steam at the required pressure and not at a higher pressure. Use steam at 0.5-1kg/cm² for open steam injection.



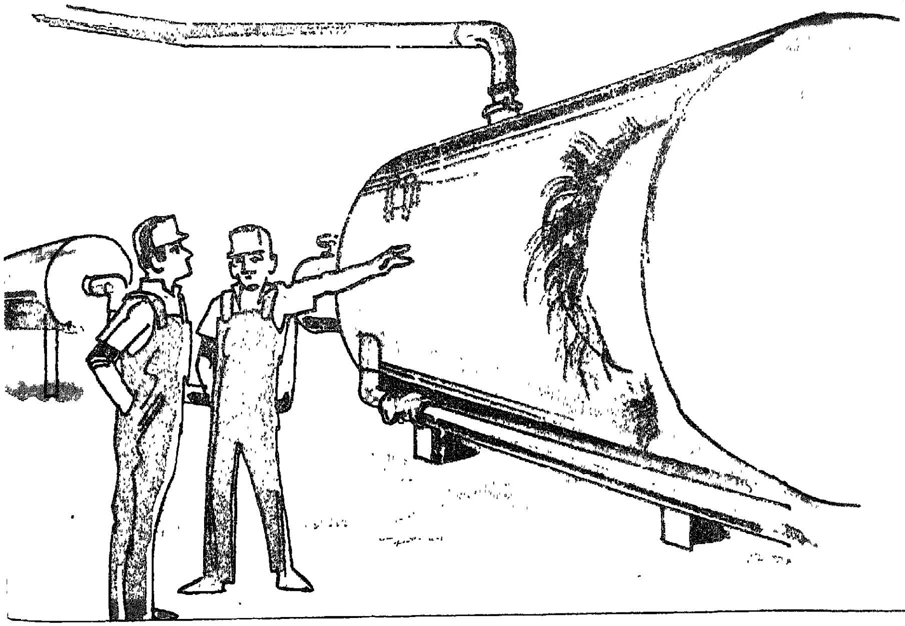
## 20. Check steam traps

Keep the sight glass clean.
Do not keep the by-pass valves open.
Report leaking traps immediately.



### 21. Use flash steam whenever it is possible

Use of flash steam reduces the load on the boiler and save fuel.



### 22. Report damaged insulation of steam consuming equipment

Damaged poor insulation of hot surface causes heat losses besides resulting in uncomfortable working conditions

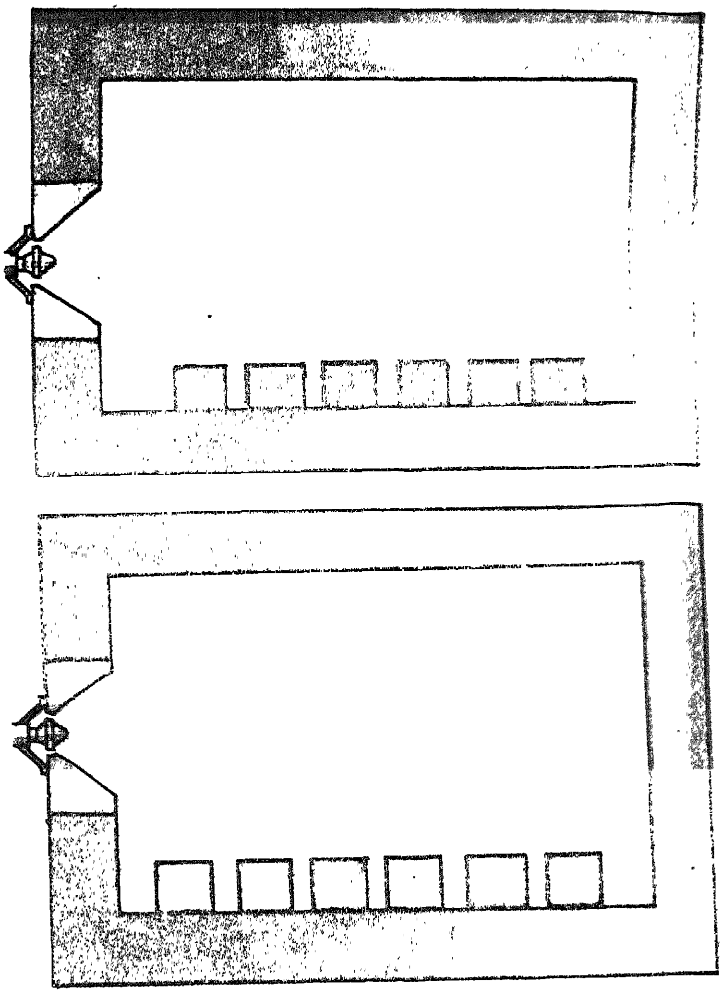
## 23. Prevent sudden boiler load fluctuation

Inform start-up/shut down of steam consuming machines well in advance so that steam supply could be properly regulated from the boiler house in time.

## VI. Furnace operation

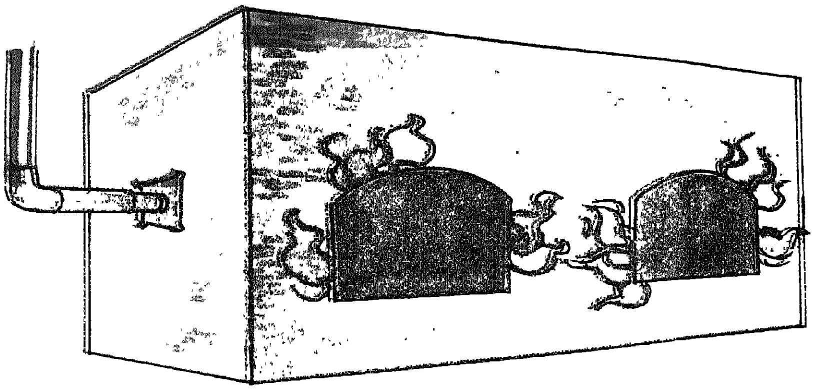
### 24. Prevent flame impingement

Align burner(s) properly. Avoid flame from touching the materials. This will not only reduce hot spots in the material, but it would also eliminate soot deposition



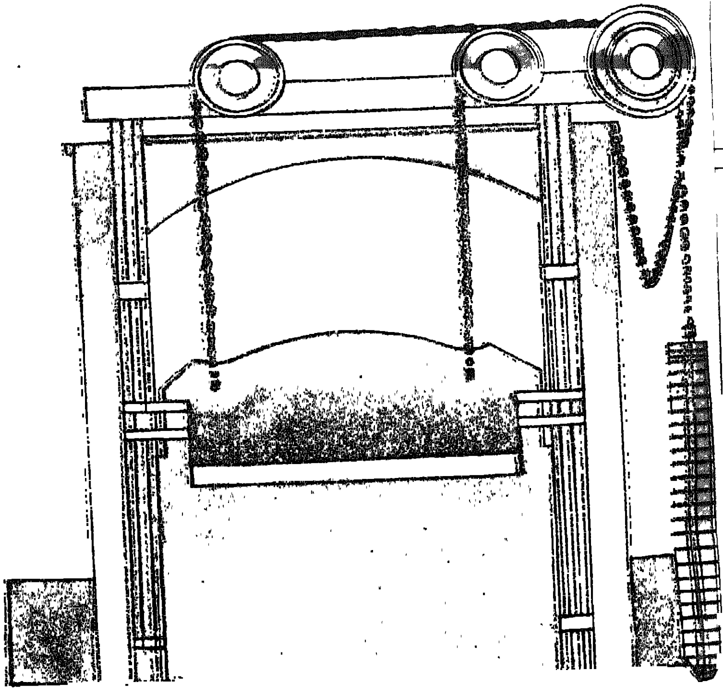
## 25. Adjust flame length

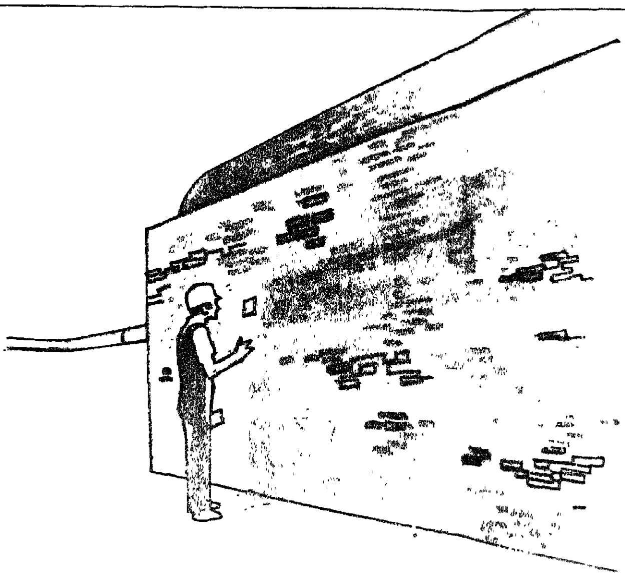
Flame leaping out of flues/ doors/openings means a direct loss of fuel.



## 26. Keep furnace doors closed:

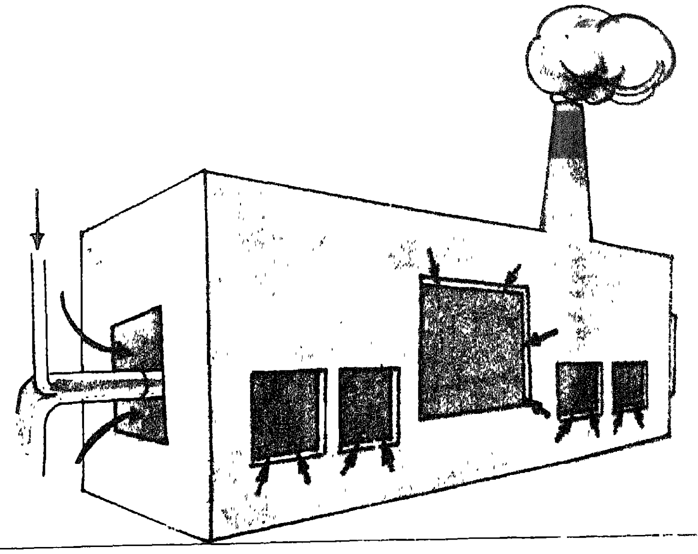
Keeping the furnace door unnecessarily open leads to wastage of fuel.





### 27. Close all openings, including inspection holes

Even small openings result in a lot of heat loss and thereby fuel wastage.

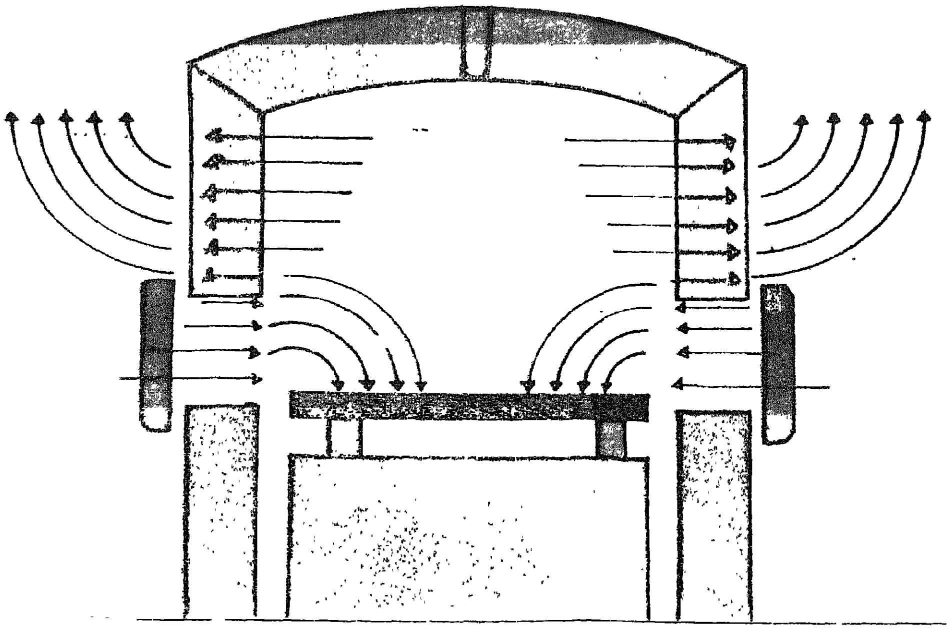


### 28. Prevent air infiltration through furnace brick work

Infiltrated air cools down the furnace and increases fuel consumption as well as scale losses.

## 29. Operate the furnace at a slight positive pressure

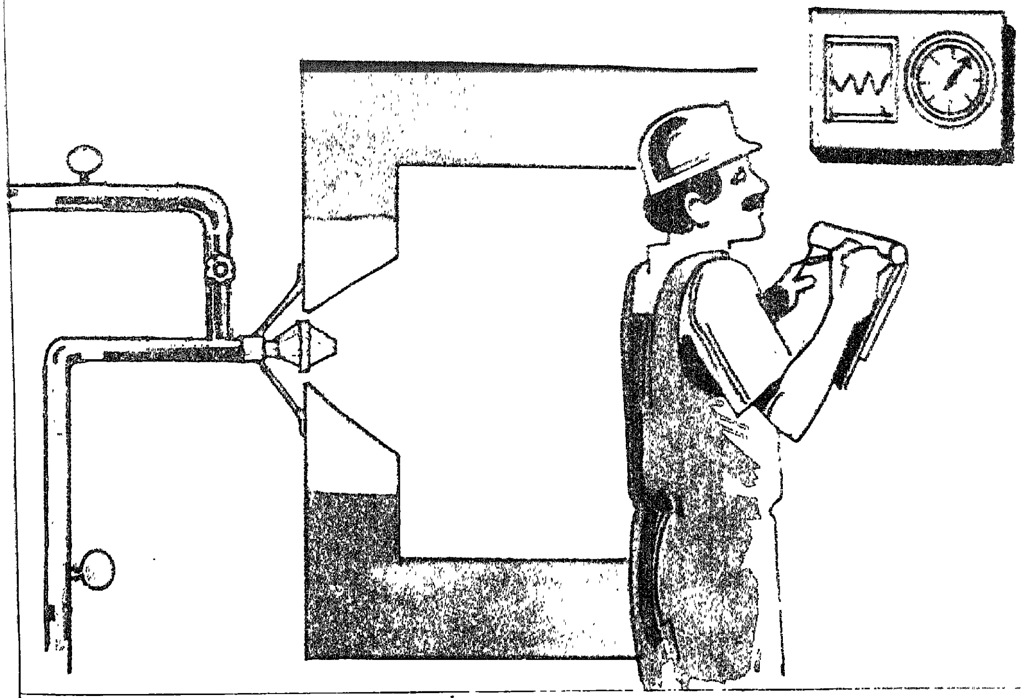
A slight positive pressure will prevent air infiltration. A simple way to check positive pressure is to hold a thread in front of the inspection hole or any other opening of the furnace. If the thread is sucked in, then the furnace is under negative pressure. If the thread is blown out, the furnace is under positive pressure.



## 30. Maintain correct furnace temperature

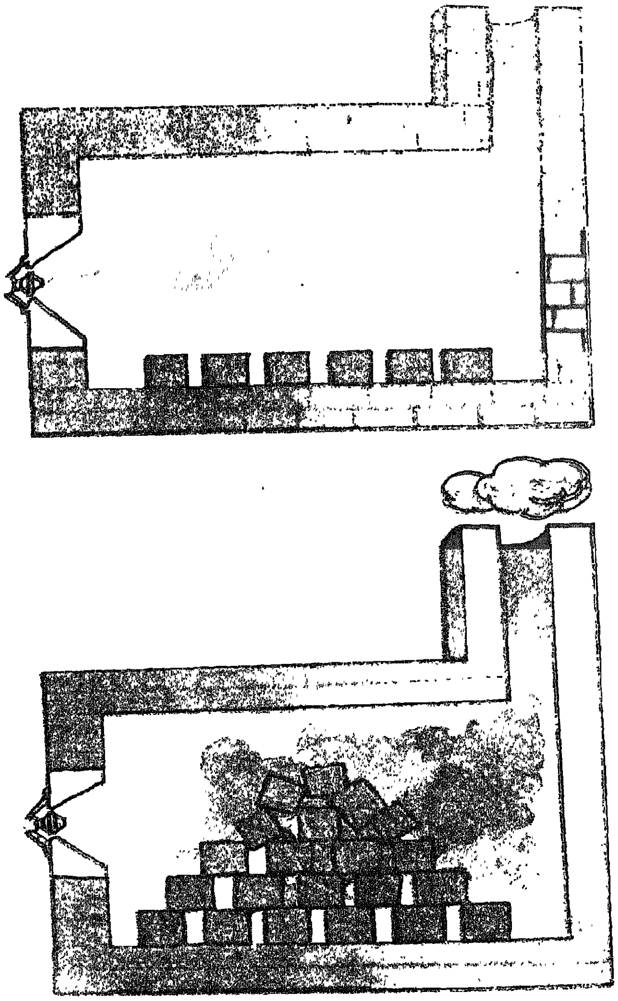
Correct temperature ensures good quality products.

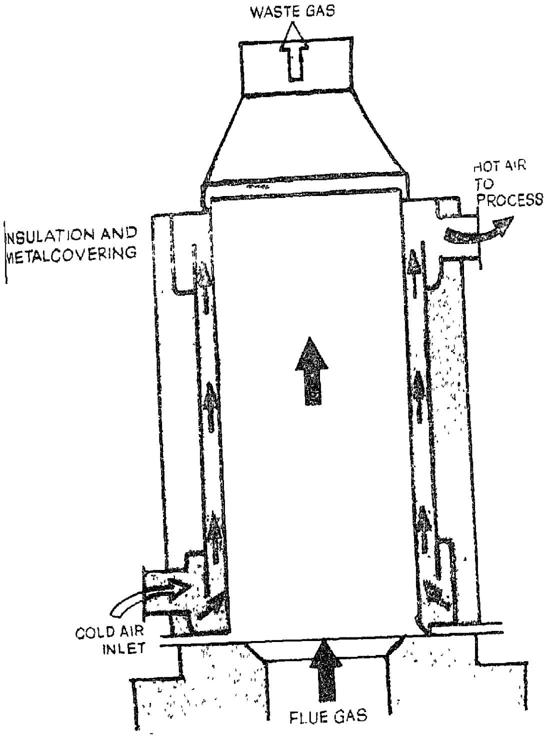
A temperature that is higher than required would only use up more fuel.



## 31. Load the furnace to its rated capacity

Overloading or underloading uses up more fuel.





## 32. Recover waste heat

A recuperator regains the heat from waste gases. Keep the gas temperature within specified limits and check the temperature of preheated air.

Increase in flue gas temperature or decrease in air-preheat temperature after the recuperator indicates the need for cleaning of the recuperator tubes.

# PCRA

Set up a few years ago in anticipation of the world-wide oil crisis that's affecting us all today, PCRA seeks to promote efficient utilisation of Petroleum Products—in homes, in industries, in farms, on roads. Because, till alternative sources of energy are found, we have to make the best use of the world's diminishing oil reserves.

Besides this guide for boiler and furnace operators, PCRA has other reference materials such as booklets, slide packages and films to promote efficient utilisation of Petroleum products in industries. The list is given below:

## BOOKLETS

On "Efficient Utilisation of Fuel Oils" for Industries.

(a) Storage, handling & preparation of fuel-oils
(b) Combustion of fuel oils & burners-operation and maintenance
(c) Efficient generation of steam
(d) Efficient utilisation of steam
(e) Fuel economy in furnaces and waste heat recovery
(f) Refractories
(g) Thermal insulation
(h) Energy audit

## FILMS

(a) Tuning of boilers & furnaces
(b) Handling of fuel oils

## SLIDE PACKAGES

Storage, handling & preparation of fuel oil
Combustion & burners
Boilers
Steam utilisation
Furnaces
Waste heat recovery
Fuel Economy in textile mills.
Water treatment

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